TEPHROSTRATIGRAPHY OF THE CHEMERON FORMATION BARINGO BASIN, KENYA

by

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The University of Utah

March 1993

THE UNIVERSITY OF UTAH GRADUATE SCHOOL

SUPERVISORY COMMITTEE APPROVAL

of a thesis submitted by

Fulbert Leon Namwamba

This thesis has been read by each member of the following supervisory committee and by majority vote has been found to be satisfactory.

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THE UNIVERSITY OF UTAH GRADUATE SCHOOL

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ABSTRACT

The Baringo Basin, in the northern Rift Valley of Kenya, has long been a focus of interest for various academic disciplines. Its deposits, ranging in age from the Miocene to the Pleistocene, with mammalian fossil localities have not only provided an opportunity for intensive study but have also raised hopes for the area as a possible source for hominid or hominoid fossils in the range 5–12 Ma. This interest has been encouraged by finding primate fossils among the numerous mammalian fossil bones collected thus far.

In the Baringo Basin chronological control for the stratigraphy of the Chemeron Formation has been scanty. Only a few dates are available, and these essentially bracket the whole formation. Since the formation is considered to be broadly coeval with the Koobi Fora, Nachukui, and Shungura Formations of the Omo Group in northern Kenya and southern Ethiopia, the focus of this study is to use tephra to correlate the Chemeron Formation with formations of the Omo Group as a basis for establishing both stratigraphic and chronologic control. The study makes it possible to compare tephrostratigraphic correlations with those made on paleontological, archeological and anthropological bases, and enable a more detailed paleogeographic and paleoenvironmental analysis.

About 15 tephra layers have been identified within the Chemeron Formation, three of which correlate with tuffs within the Turkana Basin and one of which correlates with a tuff from Kanapoi. The remaining tuffs allow for correlation between isolated outcrops in the Baringo Basin itself. This is very useful because exposures in the Baringo Basin are small and widely scattered. From the correlations established in this study it appears that the Chemeron Formation ranges in age from somewhat less than 1.6 Ma to approximately older than 4 Ma.

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Most of what has been accomplished in this study could not have been possible without the contribution of other individuals. I feel most obliged to Dr. Francis Brown, my advisor and teacher, for not only exposing me to rocks and fossils but also to other aspects of the challenges of nature in the African bush. I cannot fail to cite the role of Richard Leakey, former director of the National Museums of Kenya for having introduced me to thrills of investigating the mysteries of human origins. The other members of my committee, Dr. T. E. Cerling and Dr. D. S. Chapman, deserve special acknowledgement for their encouragement and friendship, and for critically reading this manuscript. Help from Dr. Craig Feibel, Bereket Haileab, and Steven Williams is also much appreciated.

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INTRODUCTION

Stratigraphic correlation of sedimentary strata is a task equally as challenging as it is fascinating. In East Africa this task proves difficult in the absence of suitable marker beds. The task can be complicated further if multiple tectonic events have occured during deposition of the strata under study, or after deposition was complete. Circumstances of this nature explain why this problem had to be addressed in the case of the Chemeron Formation in Kenya.

In previous studies it proved difficult to establish stratigraphic and temporal controls for the set of sedimentary beds defined as the Chemeron Formation (Hill, 1985). Ages available seemed inconsistent with the prevailing data on fauna from the formation. With three hominid fossil bone fragments and many other mammalian fragments discovered within this formation it was clearly evident that a solution had to be sought to establish the antiquity of these fossils. It is in these circumstances that the author embarked on a study of the tephra from the formation as a method of resolving the problem.

To help resolve the problem the tephra layers in the formation were examined. Volcanic glass derived from tephra was analyzed chemically and the results used for two purposes. The first was to place the tephra into a stratigraphic framework; the second was to correlate tephra layers by chemical means. This study hence presents results of a tephrostratigraphic study of the Chemeron Formation. In the process it establishes stratigraphic and temporal controls on the Chemeron Formation, using chemical, mineralogical, and physical characteristics of the tephra to correlate stratigraphic units. Previously, chronologic control was limited to dates on overlying and underlying lava flows.

The Baringo Basin, situated in the northern Rift Valley area of Kenya (Figures 1 and 2), contains Neogene sediments, most of which are exposed west of Lake Baringo. There are two principal, parallel faults in this area west of the lake, the Saimo Fault and the Kerio Fault, which trend approximately north-south. Most of the exposures of interest are parallel to the Saimo Fault and are found on its eastern flank. Exposures of the older Ngorora Formation are observed between the Saimo and Kerio faults. Shackleton (1978) described the Late Miocene, Pliocene, and Pleistocene tectonics of this area. The main focus of interest is the Chemeron Formation as mapped on the Geological Map of the Northern Tugen Hills by the East African Geological Research Unit (EAGRU). The report by EAGRU members written to accompany the map has not yet been published, but papers derived from the same field data contain a fair amount of information. Outstanding landmarks in the area include Lake Baringo, deduced by Barton et al. (1987) to be a very recent feature, only 200–300 years old, and the Kerio River Valley, which runs parallel to the Kerio Fault.

The people inhabiting the area are of the Tugen, Pokot, and Ilchamus ethnic groups. The dominant ethnic group is the Tugen, a section of the Kalenjin group of tribes who inhabit the central part of the Rift Valley province of Kenya. Members of this group are found in the Tugen Hills, on the slopes of the Saimo Escarpment and westwards into the Kerio Valley. The Pokot people, who are loosely related to the Kalenjin group, inhabit the northern, sparsely populated, part of the area and are mainly pastoralists. The Ilchamus, principally fishermen, are a branch of the Masai tribe who live on the islands and shores of Lake Baringo.

There is a good paved road from Nakuru to Kabarnet (see Figure 2) that provides access to the area. At Marigat the paved road branches and passes through Kampi ya Samaki, a fishing village and tourist spot, and ends at Loruk, a fishing village. The secondary roads that lead into the field areas are not gravelled and are cut on black cotton soil. These are nearly impassable during the rainy period even with a four-wheel drive

Figure 1. Location of the Baringo and Turkana Basins in eastern Africa.

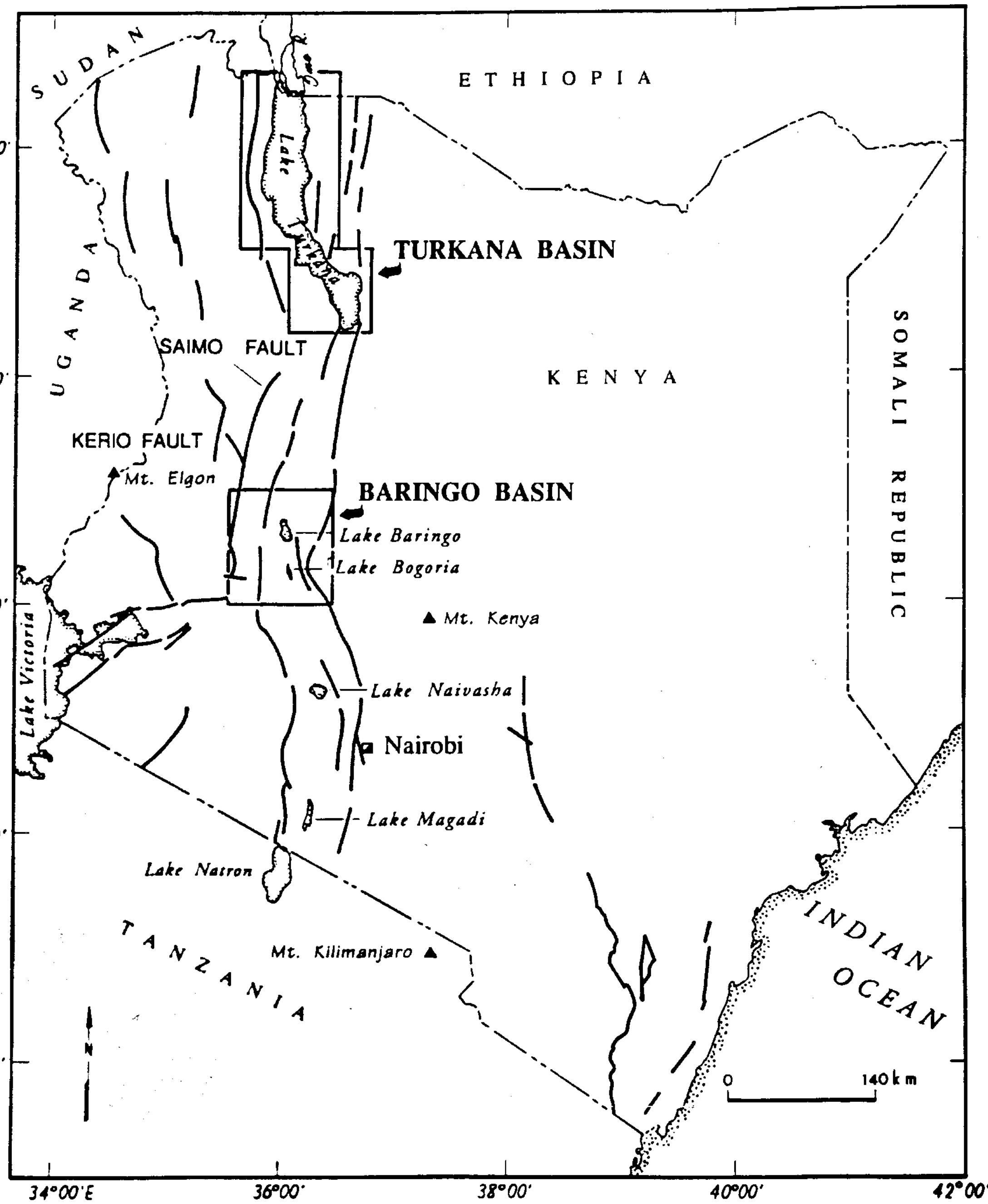
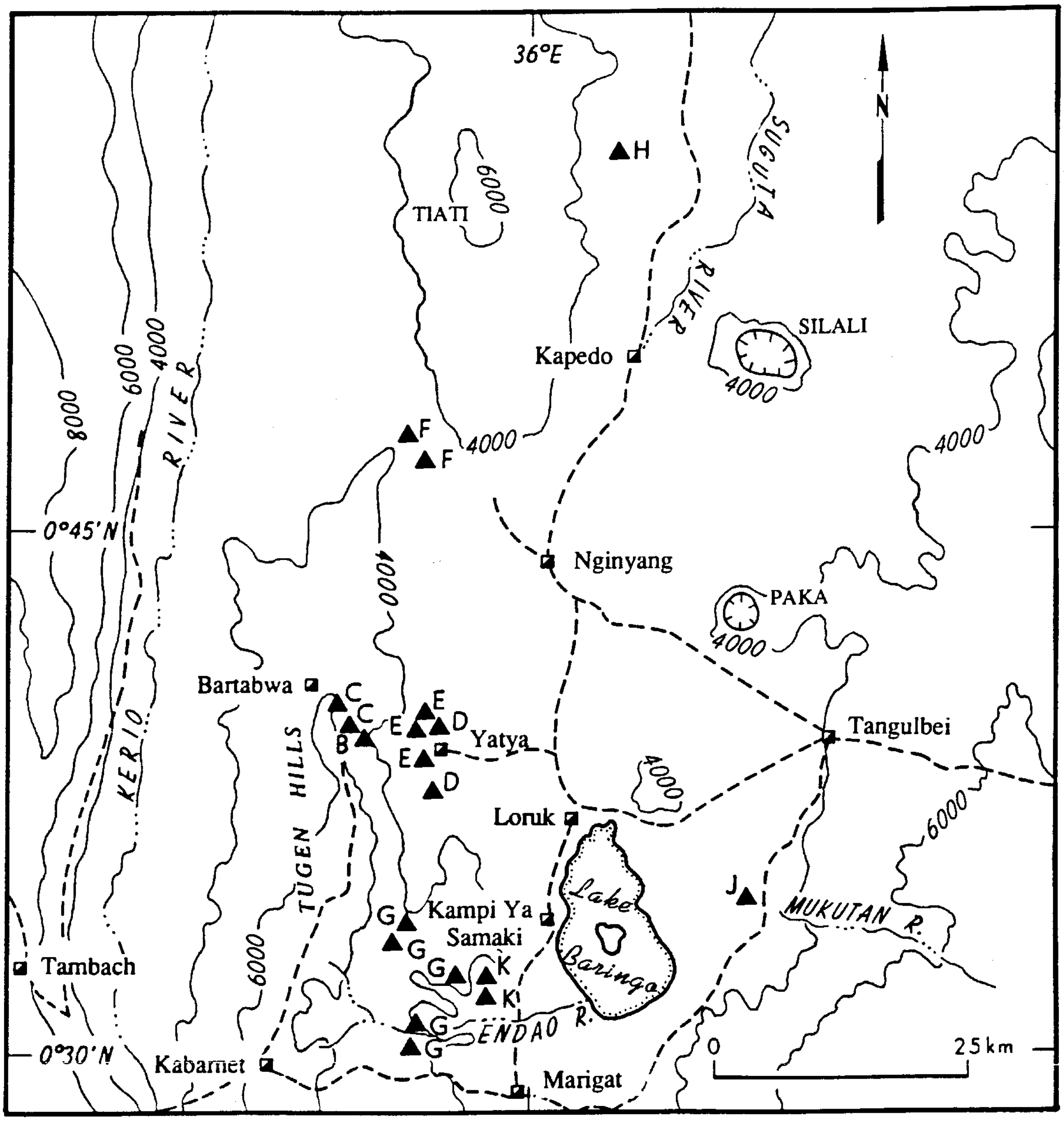

SUDAN
ETHIOPIA
Lake Turkana
TURKANA BASIN
UGANDA
SAIMO FAULT
KENYA
SOMALI REPUBLIC
KERIO FAULT
Mt. Elgon
BARINGO BASIN
Lake Baringo
Lake Bogoria
Mt. Kenya
Lake Victoria
Lake Naivasha
Nairobi
Lake Magadi
Lake Natron
TANZANIA
Mt. Kilimanjaro
INDIAN OCEAN
N
0
140 km
4°00'
2°00'
0°00'
2°00'
4°00'
34°00'E
36°00'
38°00'
40°00'
42°00'

Figure 2. Distribution of fossiliferous localities (triangles) in the Baringo Basin according to Bishop et al. (1971): A, Alengerr beds; B, Muruyur beds; C, Ngorora Fm; D, Mpesida Fm.; E, Lukeino Fm; F, Kaperyon Fm.; G, Chemeron Fm.; H, Aterir Beds; I, Karmosit beds; J, Chemoigut beds; K, Kapthurin Fm; L, Kokwob beds.


36°E
N
H
TIATI
6000
SUGUTA
RIVER
SILALI
Kapedo
4000
8000
6000
4000
RIVER
F
F
4000
4000
0°45'N
Nginyang
4000
PAKA
4000
Bartabwa
C
C
E
E
D
B
Yatya
E
D
Tangulbei
KERIO
TUGEN HILLS
4000
Loruk
6000
Lake
Baringo
J
MUKUTAN R.
G
Kampi Ya
Samaki
G
G
K
K
Tambach
6000
G
ENDAO R.
G
0°30'N
Kabarnet
Marigat
0
25km

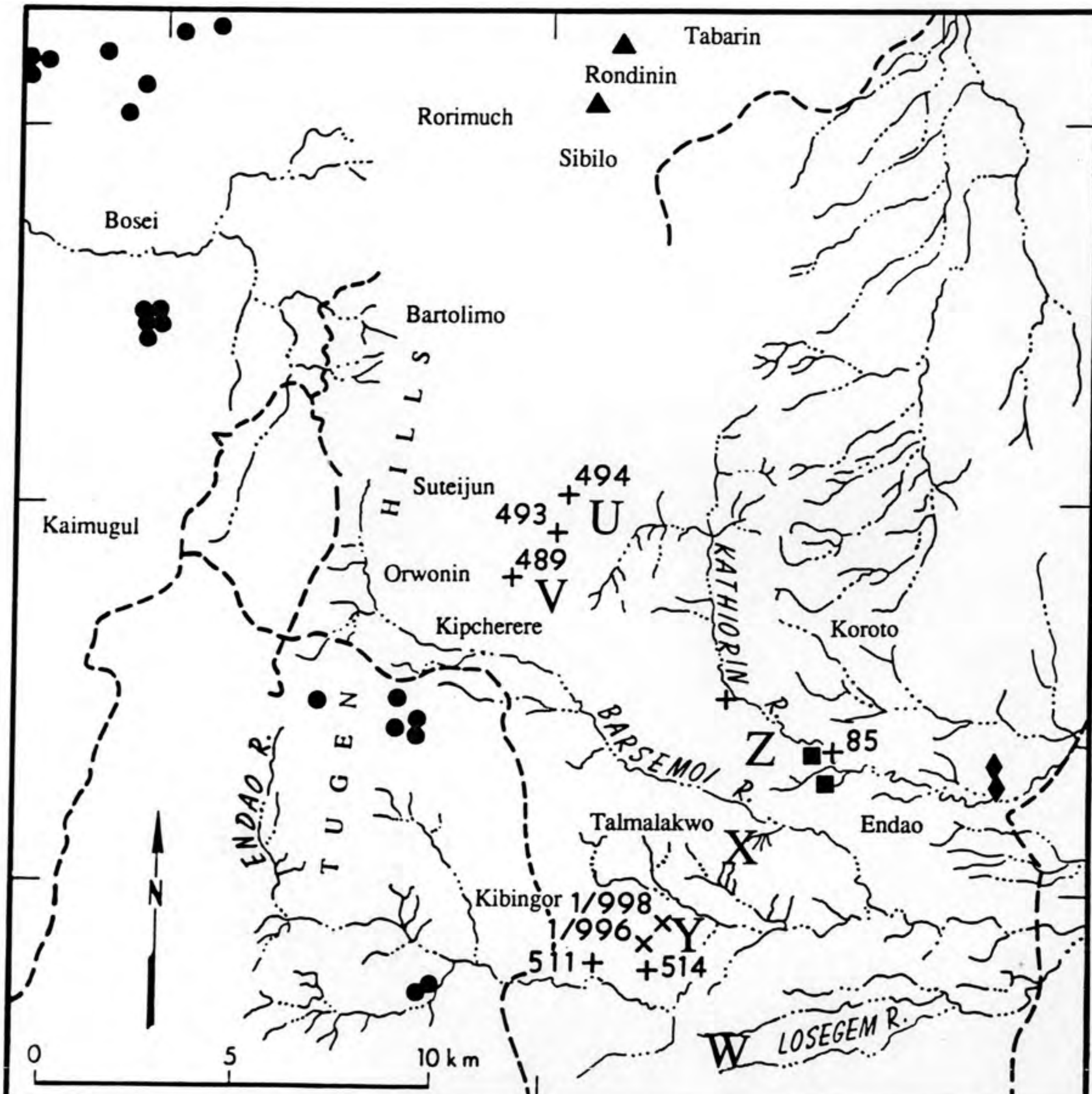
automobile. Most exposures are a few kilometers from the roads, and access paths are flanked and overgrown with thorn bushes, particularly those described as "wait-a-bit-thorns" (this is a local sobriquet grouping *Acacia mellifera* and *Acacia senegal,* species which tend to hold onto clothes with their short claw-like thorns). This kind of terrain renders mobility very difficult.

There is a police station, administrative center, three research stations, shops and other amenities at Marigat which is 20 minutes drive from Kampi ya Samaki. At Kampi ya Samaki there is the District Fisheries Office, a tourist hotel, an Anglican church mission, government health center, shops, hotels and lodging rooms. There is another police station at Loruk. With all the above facilities general logistics are not a problem. All these localities have been electrified in the last two years.

The available topographic maps are of uneven quality, and cannot be obtained without permission from the Kenya Government. The most detailed of these is the Saimo map sheet (Scale 1:50000); the Bartabwa map sheet is vague and lacks detail; the Lake Baringo map sheet is fairly adequate, whereas the one for Nginyang is hard to find.

Discrepancies exist in the use geographic names in the study area. Even though the old names are retained for the sake of continuity in the literature, certain names require clarification, because the Survey of Kenya updates names from time to time and future literature may use the modified names (Figure 3). First, the name Chemeron (accurately Chemorun, "Tamarind Countryside" in the local language (Tugen)) was derived from what was described as the Chemeron River. The same river was referred to as the Nasagum by McCall et al. (1967), but the local name, also used on recent maps, is Losegem ("the place of bees" in Tugen). Secondly, the spelling of "Kapthurin River" (and hence Kapthurin Formation) has been updated to Kathiorin (misspelling for the Tugen "Kapthiorin"). "Endao" more accurately reflects pronunciation of the "Ndau" River in the Ilchamus language, and has been adopted by the Survey of Kenya. However, to maintain

Figure 3. Map of fossil sites of the Baringo Basin. Filled circles are sites in the Ngorora Formation; triangles, sites in the Lukeino Formation; diamonds, sites in the Kapthurin Formation; squares and numbered localities, sites in the Chemeron Formation. Letters refer to measured sections as follows: U = Suteijun; V = Kipcherere; W = Losegem; X = Talmalakwo; Y = Kibingor; Z = Kapthurin.



Tabarin
Rondinin
Rorimuch
Sibilo
Bosei
Bartolimo
HILLS
Suteijun
494
493
U
Kaimugul
489
Orwonin
V
Kipcherere
KATHIORIN R.
Koroto
BARSEMOI R.
Z
85
ENDAO R.
TUGEN
Talmalakwo
X
Endao
N
Kibingor 1/998
1/996
Y
511
514
LOSEGEM R.
W
0
5
10 km

continuity, "Ndau" is retained in certain cases here. The area previously referred to as Kipsaramon has been corrected to "Kipsarman" but once again the old name is employed in this thesis for continuity.

Previously unused names appear on recent maps (e.g., Suteijun), and are also used here. Additional names acquired by the author from the local people in the field are also used. Hence a section is described from Talmalakwo ("place of wild animals" in Tugen).

PREVIOUS WORK

The earliest recorded work on the sedimentary rocks southwest of Lake Baringo was by Gregory (1921). He described a section from the Ndau river and ascribed the sediments to the Oligocene Epoch within a division he called "Nyasan." Among the early workers Leakey and Solomon (McCall et al., 1967) suggested that the sediments were of Pleistocene age, and used the term "Kamasian" to refer to the sediments. The term "Kamasian" represented a time span associated with a supposed pluvial stage. The placing of these sediments in the Pleistocene was reiterated by Fuchs (1950) who ruled out Gregory's Oligocene age on the basis of artefacts and vertebrate remains. Earlier, Fuchs (1934) had described shoreline features around the lake and mollusc-bearing strata in a short paper. An earlier description of recent shorelines in the same area was that by Nilsson (McCall et al., 1967) who had mentioned three such features. The work of Fuchs and Nilsson was questioned by McCall et al. (1967) who recognized a need for a reassessment of the facts. McCall (1967) and Walsh (1969) carried out extensive surveys in the area and deemed the conclusions by Fuchs to be irreconcilable with the evidence. They examined the area again and presented sections along several rivers, notably the Chemeron, Kapthurin, Asurein, Marigat (Kapiswa), and Molo. Details of their river section from Kapthurin are fairly well described. They mentioned that tectonics complicate the stratigraphy of the area. The most notable result of their work was the division of sedimentary beds in the area into two distinct units; the Chemeron Beds and the Kapthurin Beds. These terms are the forerunners of the Chemeron and Kapthurin Formations, which are in current use.

In their discussion of chronology they mentioned the prevailing inadequacy in the definition of the Pleistocene-Pliocene boundary referring to the work by Evernden and Curtis (1965). The work by the latter put to rest the pluvial stages and interglacial periods previously inferred by Cole, and effectively put the term "Kamasian" out of use (McCall et al., 1967).

The most notable systematic work in this area was the regional mapping program carried out by the East African Geological Research Unit (EAGRU) team under the direction of Professor B.C. King based at Bedford College (London University), the University of Nairobi and the Kenya Department of Mines and Geological Survey. Among the early workers in this team, Martyn (1967) reported finding a fossil hominid temporal fragment from Site JM85 in the Chemeron Beds. Fossil vertebrates described in Martyn's paper were further discussed in Bishop et al. (1971). Bishop and Chapman (1970) described sediments and fossils in the basin as a whole, and defined a new unit which they named the Ngorora Formation (the name is derived from the Tugen name for *Acacia mellifera*) . In their paper they presented a description of a hominid tooth from this formation, dated in excess of 9 Ma. Somewhat later, Bishop (1972) described the sedimentary rocks exposed in the basin in detail. The new units described for the first time were: the Alengerr, the Muruyur, the Mpesida, the Lukeino, the Kaperyon, the Aterir, and the Kokwob Beds. Also mentioned as fossiliferous sedimentary units were the Karmosit and Chemoigut beds (see Figure 2 for locations). Most of these units were still under study by EAGRU team members and were not defined yet as formations or otherwise.

The initial EAGRU work resulted in further interest culminating in the work of Bishop and Pickford (1975) and Pickford (1978a, b). These workers detailed the geology, paleoenvironments and fauna of the Ngorora and Lukeino Formations. Around the same time, Chapman and Brook (1978) updated the chronology of the basin and defined within it five formations, namely Ngorora, Mpesida, Lukeino, Chemeron and Kapthurin respectively in order of decreasing age. Later work by Pickford et al. (1983) tentatively assigned a humerus found in the Northern Extension of the Chemeron Formation to the species *Australopithecus afarensis*.

Renewed interest in the area is manifested by the work of the Baringo Paleontological Research Project (hereafter referred to as BPRP) based at Harvard and Yale Universities in the last 10 years. Papers emanating from this project document and describe fossils from the area and clarify certain aspects of chronology and stratigraphy of the Baringo Basin as a whole (Hill, 1985; Hill et al., 1985; Hill et al., 1986). Hill (1985) reported a hominid mandible at Tabarin in beds allocated to the Chemeron Formation (see location Figure 2). The fossil was allocated to *Australopithecus afarensis* on morphometric grounds, and also because its age was supposed to be within one million years of that of "Lucy", a well known specimen from Hadar.

The main success of the BPRP was a redocumentation of dates and faunal assemblages, these are available in the papers by Hill et al. (1985, 1986). These papers also update the stratigraphy of the Baringo Basin, and discuss the Aterir and Karmosit Beds.

The first observations on the paleomagnetic stratigraphy of the area were published by Dagley et al. (1978). These workers mainly sampled sparse igneous units, and little attention was paid to intervening sedimentary strata. For example, within the Chemeron Formation only three samples were analyzed, all associated with the Ndau Trachymugearite. Recent work by Tauxe et al. (1985) concentrated on the Ngorora Formation.

Hill et al. (1991), described hominoid teeth from Kipsaramon but gave little in the way of stratigraphic description of the locality. The latest paper by Hill et al. (1992) discussing the hominid first reported by Martyn (1967) is controversial as can be seen in Wood (1992).

REGIONAL GEOLOGY

The Baringo Basin lies in the northern rift valley of Kenya. This constitutes the northern extent of the Gregory Rift Valley, part of the Great Rift Valley of eastern Africa, a structure that runs north-south from Palestine, through the Horn of Africa and southwards through East Africa as far as Mozambique.

The Mozambique Belt contains the oldest set of rocks in the Baringo Basin. Rocks of this belt are exposed north of Birtwonin and west of Sibilo where the main rock type is hornblende gneiss. Mozambique Belt rocks are also exposed west of the Kerio river valley parallel to the Kerio Fault. Cahen and Snelling (1966) place the age of the Mozambique belt at 650–900 Ma. In earlier literature rocks of the Mozambique belt are described as basement, but this terminology has been discontinued as it lumped distinctive chronological units dating from 2800–400 Ma. The structural grain of this mobile belt defines the alignment of the faults in the Gregory Rift Valley.

Shackleton (1978) reported that rifting occurred from Tertiary time onwards and divided the volcanic phases associated with rifting into seven events. Tectonic movements and rift volcanicity are reported to be associated in space and time. The western part of the northern rift area is dominated by two parallel faults—the Saimo Fault and the Kerio Fault (King, 1978). The Uasin Gishu phonolite, dated at 13.5 Ma by Baker et al. (1971) correlates with the Tiim Phonolite in the Tugen hills. This lithological unit predates faulting in the area. The Tiim Phonolites crop out along the Tugen Hills parallel to the Saimo Fault and provide a good marker unit for deciphering tectonic events. These phonolites are underlain by the Noroyan and Saimo Formations, and the Sidekh Phonolite. The volcanic stratigraphy of the area is best expressed on sections shown on the EAGRU map by

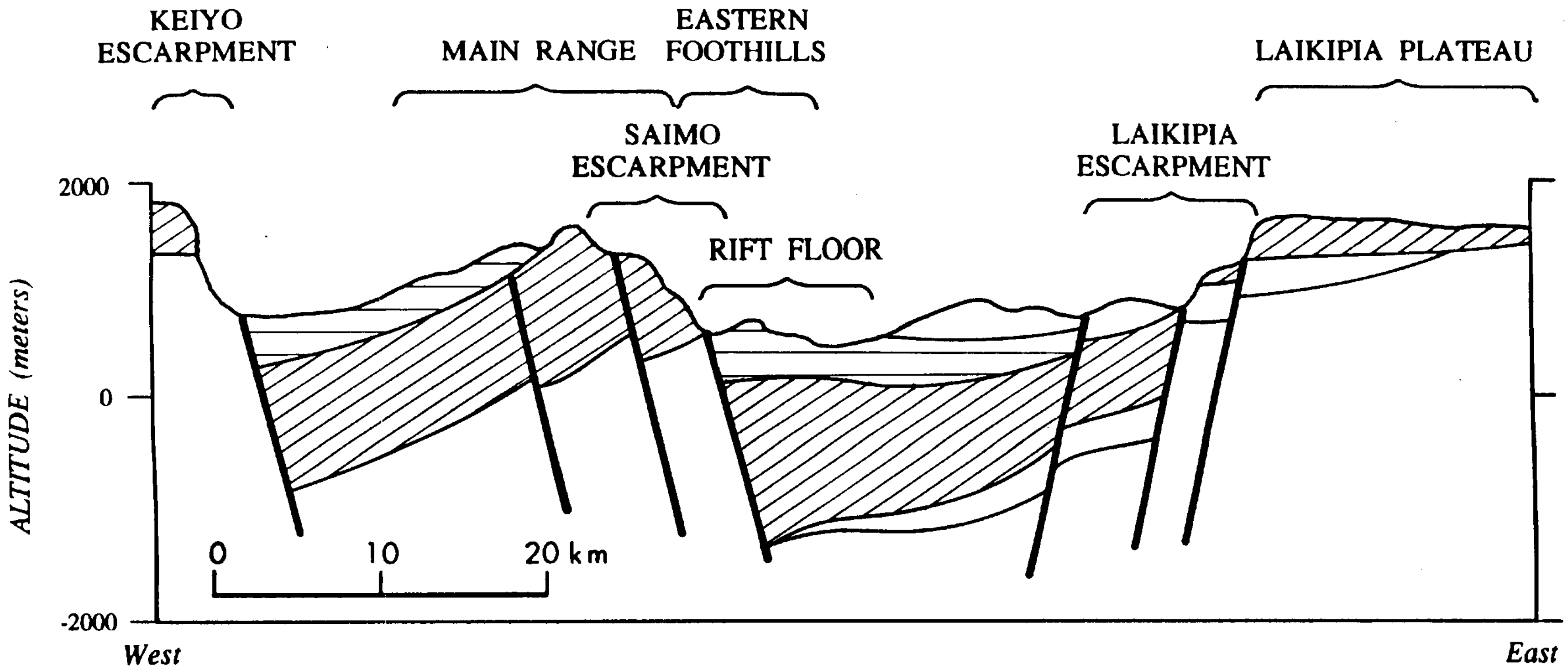
Chapman et al. (1973). The Kerio fault has little associated multiple faulting, for volcanic rocks and sediments overlying the Mozambique Belt rocks near this fault are undisturbed. The vast array of multiple faulting events and numerous volcanic episodes associated with the Saimo Fault clearly indicates the complexity of rift tectonics and volcanicity.

The general structure of the area is apparent in a cross section by Chapman and Brook (1978) adapted here as Figure 4. These workers divided the Baringo Basin into five stratigraphic units on the basis of volcanic and structural events. The first group of units, overlying the Mozambique Belt consists of the older Sidekh Phonolites, and the younger Noroyan and Saimo Formations. The Noroyan Formation consists mainly of trachytes and phonolites while the Saimo Formation consists of tephrites and basanites with local intercalations of shales and marls. Above this unit lie the Uasin Gishu and Tiim Phonolites. The first major faulting event occurs before the eruption of flood trachytes and basalts of the third group of volcanic stratigraphic units which includes the Ewalel Phonolites, Kabarnet Trachytes and Kaparaina Basalt (in decreasing order of age). Underlying the Ewalel Phonolites is the Ngorora Formation, a fossiliferous lacustrine unit. Within the Kabarnet Trachytes is the Mpesida Formation, also a fossiliferous sedimentary unit. Overlying the Kabarnet trachyte is the Lukeino Formation, another fossiliferous sedimentary unit underlying the Kaparaina Basalt. Still higher stratigraphically is the Chemeron Formation with the Ndau and Songoiwa Trachymugearites in its upper part.

In recent comments on the stratigraphy of the area Hill et al. (1985) reported that the two trachymugearites were defined to be within the Chemeron Formation. The Chemeron Formation contains several tuffs as do other sedimentary units in the basin. An angular unconformity at the top of Chemeron Formation separates it from the younger undisturbed beds of the Kapthurin Formation. Associated with this latter unit are Quaternary flood lavas and central volcanoes of the Rift Centre, notably the Chemakilani Trachymugearites, Ribon Trachyte, Lokwaleibit Basalts, Loyamarok Trachyphonolite, and the Lake Baringo

Figure 4. Generalised cross section of the Baringo basin, showing structural regions (adapted from Chapman and Brook, 1978).

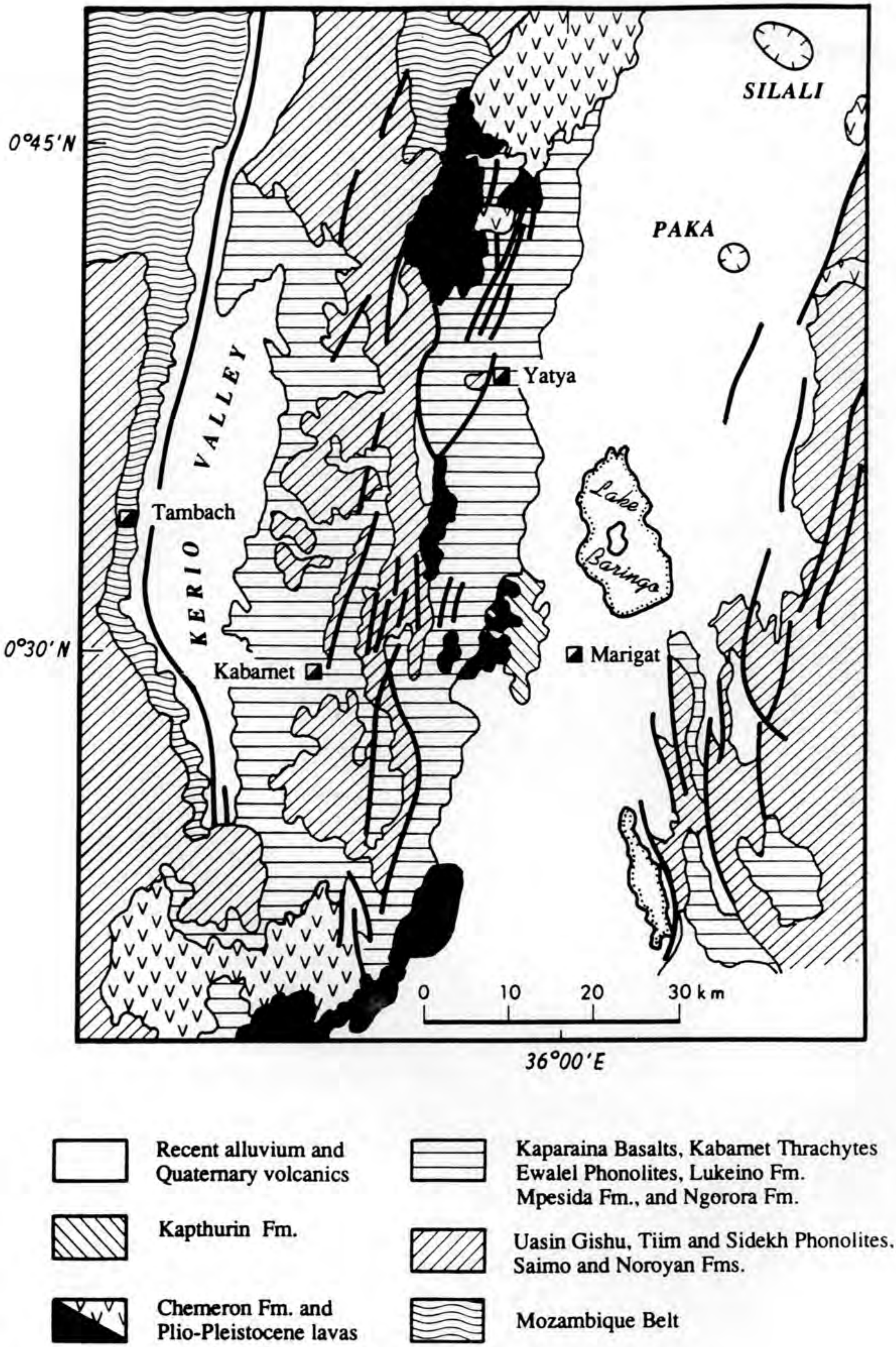
TUGEN HILLS


KEIYO ESCARPMENT
MAIN RANGE
EASTERN FOOTHILLS
LAIKIPIA PLATEAU
SAIMO ESCARPMENT
LAIKIPIA ESCARPMENT
RIFT FLOOR
2000
0
-2000
ALTITUDE (meters)
0
10
20 km
West
East

Trachyte. The regional geology of the Baringo Basin is summarized in Figure 5, and the regional stratigraphy is shown on Figure 6.

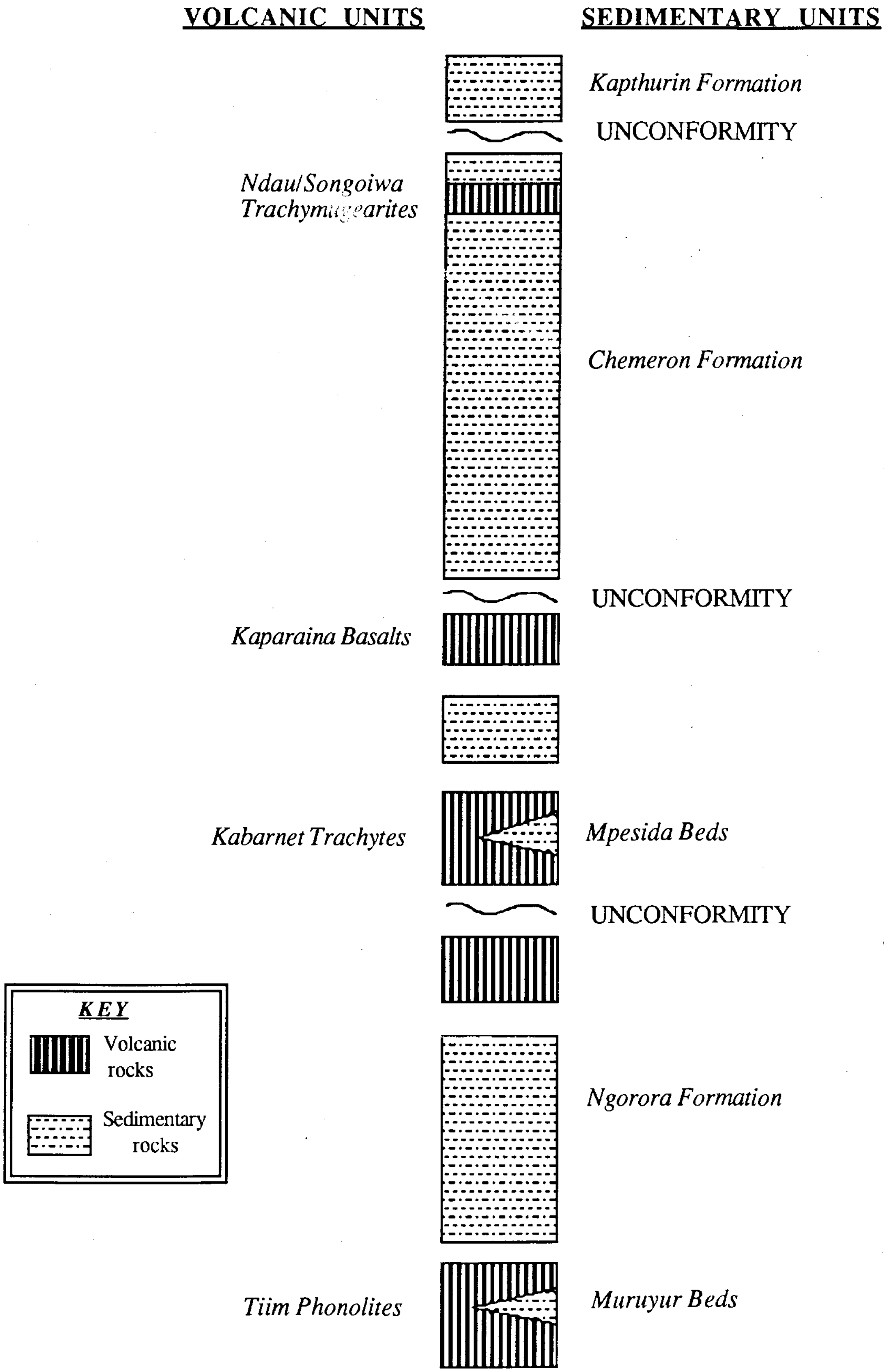
The Kaperyon Formation, originally thought to be coeval only with the Chemeron Formation (Bishop et al., 1971), was later split into three different units correlated with the Ngorora, Lukeino, and Chemeron Formations respectively (Pickford, 1975).

Figure 5. Geological map of the Baringo Basin (adapted from Chapman and Brook, 1978).



SILALI
PAKA
0°45'N
0°30'N
KERIO VALLEY
Yatya
Tambach
Lake Baringo
Marigat
Kabarnet
0
10
20
30 km
36°00'E
Recent alluvium and Quaternary volcanics
Kapthurin Fm.
Chemeron Fm. and Plio-Pleistocene lavas
Kaparaina Basalts, Kabarnet Thrachytes Ewalel Phonolites, Lukeino Fm. Mpesida Fm., and Ngorora Fm.
Uasin Gishu, Tiim and Sidekh Phonolites, Saimo and Noroyan Fms.
Mozambique Belt

Figure 6. Sedimentary stratigraphy of the Baringo Basin, Kenya (adapted from Hill et al. 1985).


VOLCANIC UNITS
SEDIMENTARY UNITS
Kapthurin Formation
UNCONFORMITY
Ndau/Songoiwa Trachymugearites
Chemeron Formation
UNCONFORMITY
Kaparaina Basalts
Kabarnet Trachytes
Mpesida Beds
UNCONFORMITY
Ngorora Formation
Tiim Phonolites
Muruyur Beds
KEY
Volcanic rocks
Sedimentary rocks

EXISTING PROBLEMS WITH CHRONOSTRATIGRAPHY AND PALEONTOLOGY OF THE NEOGENE BEDS OF THE BARINGO BASIN

There are several unresolved controversies concerning the stratigraphy of what is described as the Chemeron Formation. As has been noted, McCall et al. (1967) defined the Chemeron Beds as a lithological unit distinct from the Kapthurin Beds. The Chemeron Beds were defined to lie below a lava, probably the Ndau Trachymugearite. Martyn (1967) redefined this boundary at an unconformity above the Ndau Trachymugearite. In his Ph.D. thesis Martyn (in Martyn (1969), cited in Bishop et al. (1971)), defined two basins of deposition, one in the Chemeron, Ndau, Asurein and Barsemoi river valleys (near each other), and the other at Kipcherere, west of the first area. Martyn did not attempt to define the relative ages of the two basins, but he noted from their fauna that they were of similar age. He divided the Chemeron beds into five lithological units as follows: Basal Beds (0–45 m), Lower Fish Beds (up to 100 m), Lower Tuffs (3–5 m), Upper Fish Beds (up to 80 m), Upper Tuffs (6–30 m).

The Basal Beds were defined as resting on basalts (likely to be Kaparaina Basalt) and were said to be deposited in a depression not exceeding 8 km from north to south. Whereas the definition and location of the Basal Beds is not a problem, the use of the terminology "Basal" may require revision in view of recent evidence. Numerous faults make it very hard to place the "Basal Beds" stratigraphically. The faulting even raises the question of whether the "Basal Beds" are a coherent single unit. As will be shown, the "Basal Beds" (*sensu* Martyn (1967)) are not at the base of the formation.

The Kipcherere Beds (as defined by Martyn 1967) overlie the Kaparaina Basalt, but are otherwise stratigraphically unrelated to Martyn's Basal Member. The fossils from this unit are reported to be older than those from the Basal Member of the Chemeron Formation (Hill et al., 1986). Pickford (1983) recommended that the unit should perhaps be treated as a formation independent of the type section. The relation between the beds at Kipcherere and the "Basal Beds" is discussed later in this thesis. The remaining subdivisions of the type section of the Chemeron Formation are not problematic, and the transition from the top of the Basal Beds to the Lower Fish Beds is fairly straightforward.

Since Martyn (1967), dating of the Chemeron Formation has been controversial. Some issues were raised by Bishop et al. (1971), among which is the stratigraphic placement and distribution of vertebrate fossils. Another prominent issue is the definition of the Kaperyon Formation, whose fauna is described by Bishop et al. (1971) and tentatively placed in the Chemeron Formation. Pickford (1978b) challenged the definition, and after examining the fauna, redefined the Kaperyon Formation as consisting of parts of the Chemeron, Lukeino and Mpesida Formations. When Bishop et al. (1971) was published there were no secure dates on the Chemeron Formation.

Bishop et al. (1971) challenged the placing of certain taxa from locality JM 91(and JM 90) in the "Basal Member" because they appeared different from "Basal faunas" elsewhere in the formation. It is notable that Bishop et al. (1971) treated the "Basal Beds" defined in Martyn (1967) as a member of the Chemeron Formation, and also provided the first definition of the Chemeron Formation. From the work reported here, strata of the Kipcherere depositional basin are known to be generally older than those in the "Type Section," a term Pickford et al. (1985) consider more appropriate for the Chemeron depositional basin of Martyn (1967).

Another issue is the relation of the Aterir Beds (~4 Ma) and the Karmosit Beds (interpreted as less than 3.4 Ma) to the Chemeron Formation. These two localities overlap temporally with the Chemeron Formation and a correlation between the two ought to be secured. It is not clear what basis was used to estimate the age range, but the presence of *Notochoerus* defines an upper temporal limit of about 2.5 Ma for Karmosit.

The earlier work did not resolve clearly the problem of relative ages within the Chemeron Formation. Chapman and Brook (1978) discuss the chronostratigraphy of the Baringo Basin, but did not manage to establish a secure date for the top of the Kaparaina Basalt. Dates available at the time range from as old as 8.2 Ma to as young as 3.96 Ma. They mentioned in the same publication that basalts may give anomalous K-Ar ages because of low K-content, and remarked that such dates were known from other areas in Kenya. Later workers agree that an age in the range 5–6 Ma is more appropriate, and the BPRP (in Hill et al., 1986) present several ages close to 5.65 Ma. From field observations the Kaparaina are a suite of basalt flows, and the sheer variability in definition of the base of the Chemeron Formation calls for more work.

Chapman and Brook (1978) also report two ages for lavas from Ribkwo Volcano which underlie the Kaperyon Formation. The two dates at 3.7 and 4.9 Ma suggest a temporal overlap of the Kaperyon Formation with the Chemeron Formation.

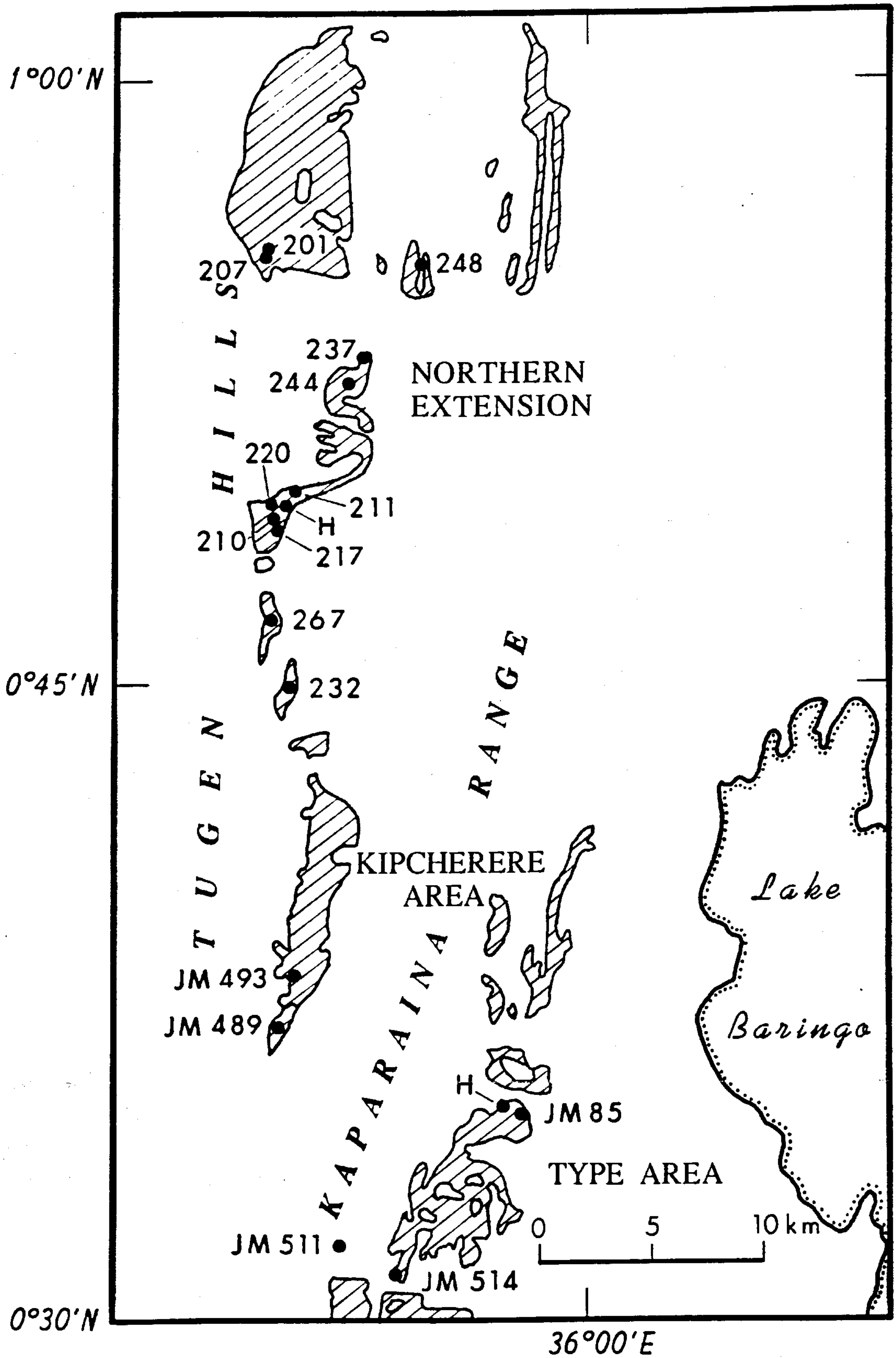
In addition to the above arguments, recent workers contend that a date older than 4 Ma for the majority of sites in the Chemeron Formation is appropriate (e.g., Hill et al., 1985). Earlier this argument had led to the challenging of the context of paleontological material from site JM90 (and JM91) reported by Martyn (1967). The presence of *Elephas recki, Papio baringensis,* and *Paracolobus chemeroni* implied a date younger than 3 Ma for the "Basal Beds" at the site. Bishop et al. (1971) considered this evidence anomalous and insisted that the geological evidence did not support that view. It was evident that the "Basal fauna" from elsewhere in the formation was older than 3 Ma, implying a lack of coherency and uniformity in defining which beds belonged to the "Basal Member." At the Kibingor fossil site, parts of the Lukeino Formation may have been described as "Basal Chemeron."

Because stratigraphic positions of individual fossils at collection localities from the Chemeron Formation are not well documented, the argument of Hill (1985) that the majority of sites are older than 4 Ma is quite weak. There are no statistics available on the stratigraphic distribution of the specimens reported in faunal lists so what is meant by the 'majority of sites' is not clear. Most of the specimens may come from a single stratigraphic interval.

A hominid mandible (interpreted to be *Australopithecus afarensis*) collected from Tabarin (Figure 3) is mentioned by Hill (1985). The age of the mandible was suggested to be only a little younger than 5 Ma.

Pickford et al. (1983) reported a hominid humerus from Locality 2/211 in the Northern Extension of Chemeron Formation (Figure 7). An age of 5.3 Ma reported for a tuff in the vicinity of the fossil find and the associated mammalian fossil fauna were used to suggest an age for the fossil.

Figure 7. Regional setting and outcrop map of the Chemeron Formation. Numbers refer to fossiliferous localities; H = Hominoid (adapted from Pickford et al., 1983).


1°00'N
0°45'N
0°30'N
36°00'E
201
207
248
237
244
NORTHERN
EXTENSION
220
211
H
210
217
267
232
TUGEN HILLS
KAPARAINA RANGE
KIPCHERERE
AREA
JM 493
JM 489
H
JM 85
TYPE AREA
JM 511
JM 514
0
5
10 km
Lake
Baringo

METHODS OF STUDY

In the attempt to correlate between the Baringo and Turkana Basins, the Chemeron Formation was the natural place to start as the few available dates showed it to overlap temporally with the Koobi Fora Formation, whose chronology had been securely established (Feibel et al., 1989). The first venture to the field by the author was with the BPRP team in the summer of 1989, for a reconnaissance of the tephra in the Chemeron Formation. The idea, suggested to the author by F. H. Brown, was to collect all possible tephra and also to look out for blue-gray tuffs which might prove useful for long distance correlation. The field methods were to be similar if not identical to those used by Haileab (1988), but the task proved to be more complicated. The author observed that the tephra in the field fell into a broad color dichotomy, one group was blue gray and the others were greenish brown. The first group was not a problem because 500–600 grams of material from the field was adequate to separate enough glass for analysis by X-ray fluorescence methods (XRF). The second group was more highly altered and the glass content was very small. Therefore many of the tephra collected during the reconnaissance visit did not provide sufficient glass for XRF analysis. Also it was difficult to differentiate fine grained examples of the greenish brown tuffs from completely altered tuffs and claystones in the field. As a result some of the supposed tephra collected during the first season turned out to be clays on microscopic examination. Another objective of the preliminary expedition was to identify materials for dating (such as pumice clasts). This turned out to be futile, because pumices found by the author were too small to yield sufficient feldspar for conventional K/Ar dating, although dating by single crystal laser fusion might be possible.

Insofar as possible the sampling was done from the base to the top of the section, but again there was another complication. Exposures in this region are scattered and isolated, and the sediments highly faulted so that same stratigraphic level was sometimes resampled when crossing from a downfaulted section to an upfaulted one or vice versa.

Two numbering systems are applied to tuffs sampled for this exercise. The first is that of T. E. Cerling (Univ. of Utah), and the other that of the author. In the first, the term "BAR" was used to represent Baringo, (the sampling area), while "-n" was the sample number. In the second system the term "BF" was an amalgamation of "B" for the field area and "F" the initial for the collectors first name. The two systems arose because Dr. Cerling collected samples on behalf of the author at a similar time (1989) so two different sample nomenclatures were used to avoid ambiguity.

In the second and third visits to the basin, wider areas were covered than previously and sections were measured in the associated areas. Tephra and other materials of geological interest were collected during these later visits as well.

In the laboratory the samples were crushed by mortar and pestle and sieved to -60 +120 mesh. The Baringo samples were dried at 60 °C as most of them were wet from the field and adhered to the mesh. After sieving, the material was washed several times in warm water, then treated with 10% nitric acid, and finally with 5% hydrofluoric acid. These reagents were used to remove clay and suspended material, calcium carbonate, and detrital clay respectively. The purpose of this process was to end up with glass shards free of these impurities and also free of alteration products.

The next step was to separate the glass shards from magnetic minerals, quartz, feldspar, mica, and other minerals that remained after washing. This was achieved by a Frantz Isodynamic magnetic separator. By passing the material through a magnetic field the various mineral grains were separated on the basis of their magnetic susceptibility. After preliminary separation the purity was checked by immersing a few thousand grains in oil, and estimating the percentage of impurities. Repeated magnetic treatments and HF cleanings were carried out until the sample was considered pure enough for XRF analysis, that is a purity of at least 99.5%.

For samples which could not be purified on the Frantz, a heavy liquid, sodium polytungstate, was used as a means of separation. This worked quite well for some samples, but not for others. Standard techniques and centrifuging were applied to this end. Traces of the heavy liquid were removed by repeated washing of separates in distilled water. Haileab (1988) ran a control experiment to compare the effectiveness of the heavy liquid and magnetic separation methods and observed that the heavy liquid method compared well with magnetic separation.

For XRF analysis, the purified glass separates were made into pellets by mixing them with cellulose in a 4:1 ratio by weight, and grinding the mixture in acetone in an automatic mortar. The resulting powder was pressed into an aluminum backing cap at 15 tons/cm^2. Sample weights were normally 2 g but some were as low as 1.4 g and others as high as 2.4 g (this being the weight of glass only in the mixture).

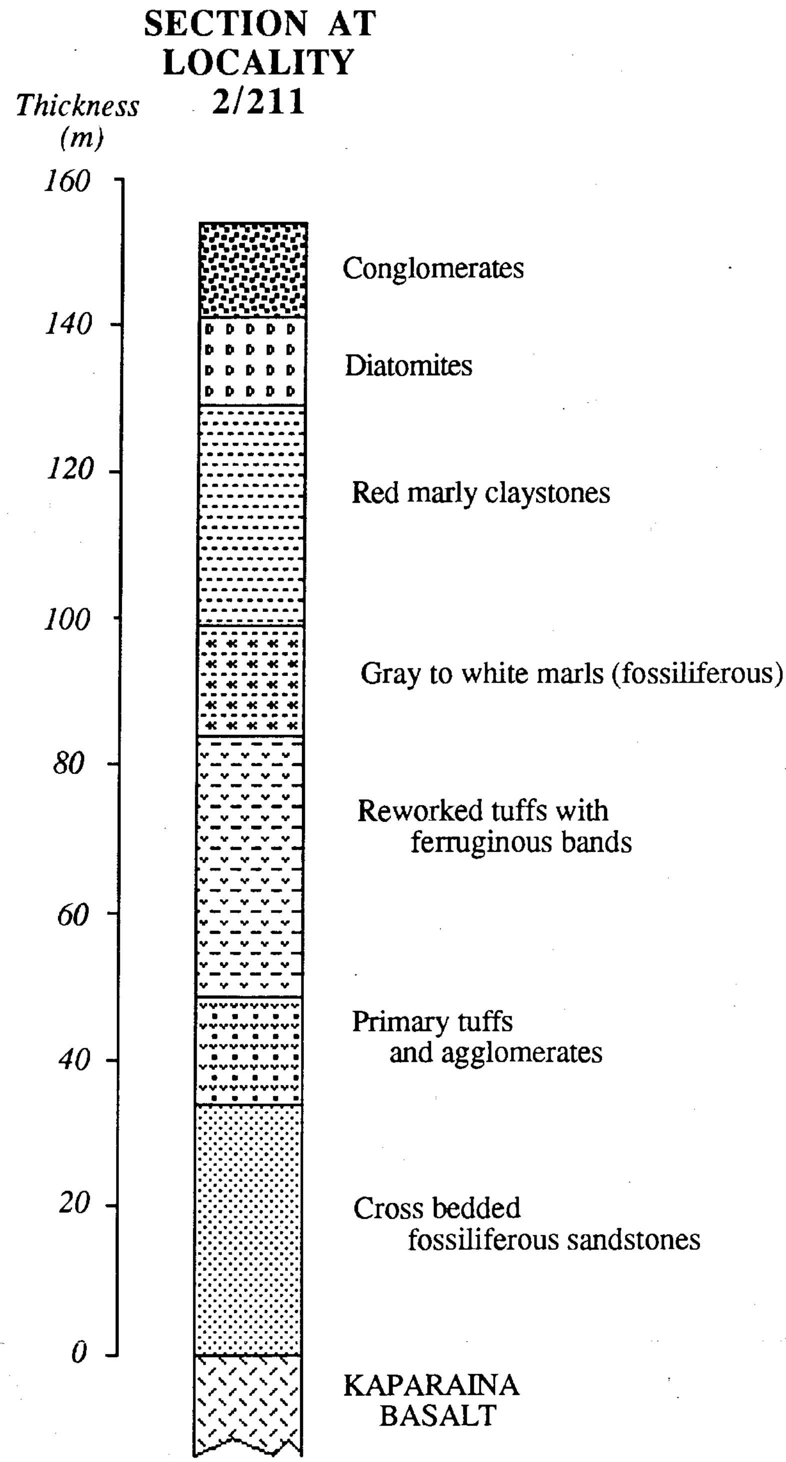
The samples were analyzed using an ARL 8410 sequential X-ray fluorescence spectrometer for Ba, Ca, Fe, K, Mg, Mn, Na, Nb, Rb, Sr, Ti, Y, Zn and Zr. For the high- iron, low-silica samples (the greenish tephra), obsidians from Kenya that had been previously analyzed by XRF and electron microprobe techniques were used as standards. Previously analyzed tephra from the Turkana Basin were used for the low-iron, high-silica tephra. Compositional data on the standards are given in the Appendix. The data were corrected for drift, and the average values compare favorably with those obtained from the electron microprobe.

GEOLOGY OF THE CHEMERON FORMATION

The Chemeron Formation is defined as Pliocene and Pleistocene sedimentary and volcanic rocks overlying the Kaparaina basalt that are bounded above by an angular unconformity. These rocks include both fluviatile and lacustrine sediments, and also contain volcanic flows, tuffs and an ignimbrite. Pickford et al. (1983) provide a lithostratigraphic description of the deposits thought to be the oldest part of the formation in an area called the Northern Extension. The "Type Section" of Martyn (1967) includes only the youngest part of the Chemeron Formation where the Ndau and Songoiwa Trachymugearites are exposed. The upper boundary of the formation is an angular unconformity between the dipping beds of the Chemeron Formation and the flat-lying beds of the overlying Kapthurin Formation. Figure 7 shows the location of strata exposed in the Northern Extension relative to the other exposures of the Chemeron Formation. In the text below, tephra layers useful for local or regional correlation are named in the appropriate section. The basis for the correlations is discussed in a later section of the thesis.

Northern extension. A 154 m section at Pelion (site 2/211 in Figure 7) consists of sedimentary rocks (Figure 8) that begin with 15 m of fossiliferous fluvial and lake margin sediments overlain by reworked tuffs about 13 m thick (Pickford, 1984). These are overlain by a 15 m thick primary tuff and agglomerate, the Cheseton Lapilli Tuff; feldspar crystals from a pumice bomb in this tuff yielded K-Ar ages of 5.02, 5.09, and 5.11 Ma, averaging 5.07 Ma (Pickford et al., 1984). Above this is 33 m of tuffaceous beds in which some layers are strongly ferruginized. Overlying these are marly grayish to white sediments. The basal parts of the marls are fossiliferous. At the top of the section are more than 50 m of red marls, diatomite and sandy tuffs exposed in steep cliffs.

Figure 8. Stratigraphy of the Chemeron Formation, Northern Extension, at Pelion, Site 2/211 (adapted from Pickford et al., 1983).


SECTION AT
LOCALITY
2/211
Thickness
(m)
160
140
120
100
80
60
40
20
0
Conglomerates
Diatomites
Red marly claystones
Gray to white marls (fossiliferous)
Reworked tuffs with
ferruginous bands
Primary tuffs
and agglomerates
Cross bedded
fossiliferous sandstones
KAPARAINA
BASALT

Pickford et al. (1983) surmise that in the lower part of the section there is a facies change from fluvial to fully lacustrine conditions, and also that this facies change occurs at increasingly higher stratigraphic levels from east to west. This was interpreted to represent a systematic transgression of the apron of fluvial sediments derived from the neighboring western hills at the time.

Tabarin, south of Pelion, is another fossil site overlying the Kaparaina Basalt. According to existing maps these exposures ought to correlate with Pickford's Northern Extension which is in agreement with the fauna. Hill (1985) describes the stratigraphy and reports 20 m of fine to medium grained sediments above the Kaparaina Basalt, in turn overlain by a tuffaceous unit about 10 m thick. The latter unit, described as ignimbritic, baked the underlying sediments and grades upwards to a coarse pumice tuff that is also pumiceous at the base.

The author collected the ignimbrite (BF91002) and the associated pumiceous tuff (BF91005). Hill (1985) describes the overlying units as 20 m of mainly yellow and orange silts and sands, overlain by a fossiliferous dark brown coarsely bedded ferruginous conglomerate containing poorly sorted igneous clasts. Hill (1985) contends that much of the surface fossil material is derived from this conglomerate unit. A tuff (BF91006) below the surface position of the fossil was collected for laboratory analysis.

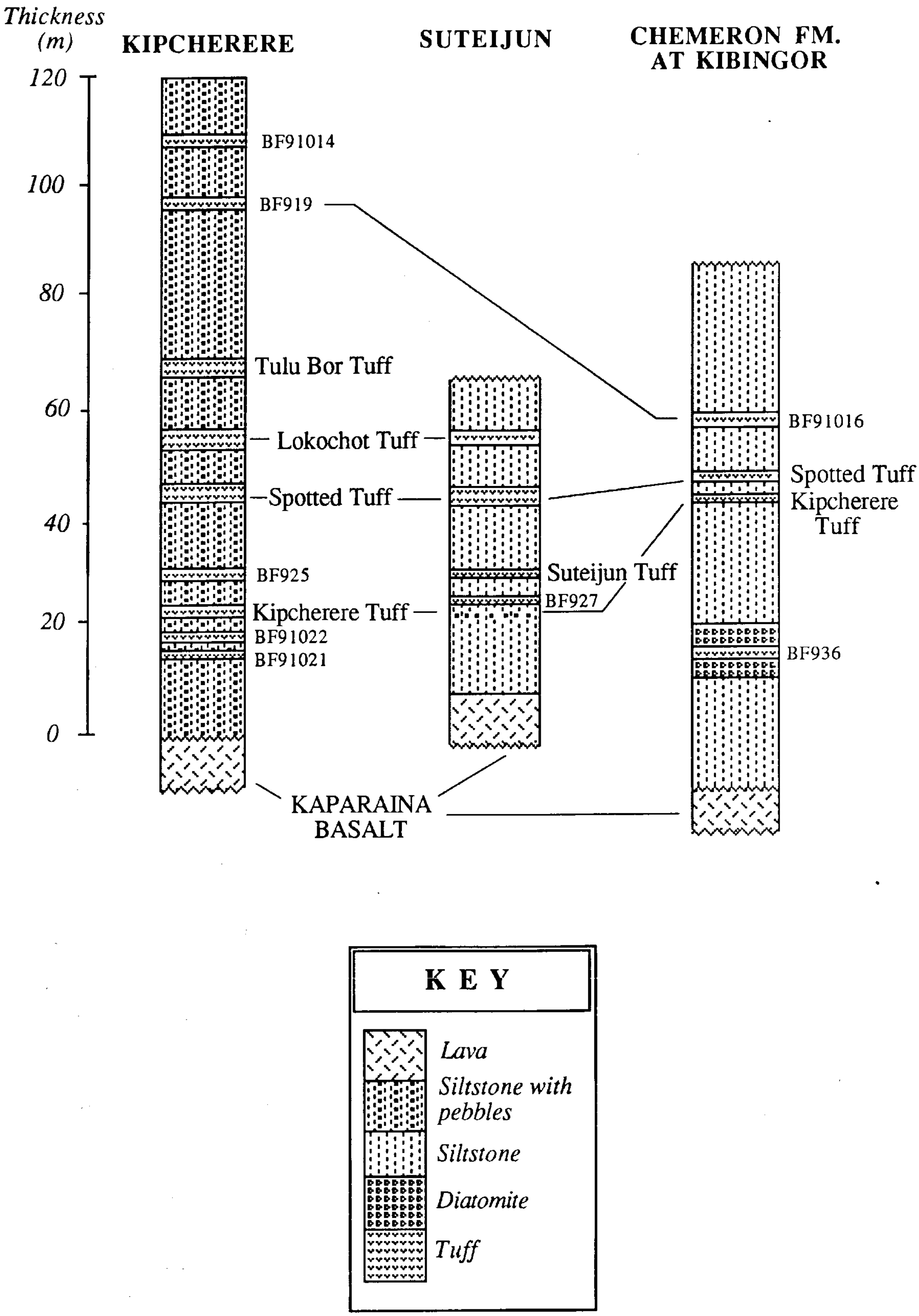
The fossil molluscs, fishes, and reptiles at Tabarin are types that existed for long periods without evolving and are hence not very useful in estimating the age of the formation. However, the mammals are somewhat more useful. Of the primates (cercopithecoids and papionine) collected, none were identified to specific levels and are hence not useful. The hominid mandible is significant but its original stratigraphic position is not well known. Among the carnivores, *Enhydriodon cf. campani* and a hyaenid resemble forms found at Kanapoi; the hyaenid also occurs at Kaiso (J. Barry pers. comm. to Hill (1985)). The proboscideans are of three kinds: Gomphotheriidae (*Anancus kenyensis)*, Elephantidae (*Primelephas gomphotheroides)*, and Deinotheriidae

(*Deinotherium bozasi*). Among the suids *Nyanzachoerus jaegeri* is observed at Tabarin. *Nyanzachoerus jaegeri* and *Anancus kenyensis* were used to set the date of the mandible at around 4 Ma.

Kipcherere area. Farther south are the sedimentary beds at Kipcherere where a measured section totals 120 m (Figure 9). The section was measured in the locality marked **V** in Figure 3. Briefly, above the weathered surface of the Kaparaina basalt is 15 m of siltstone overlain by the lowest tephra layer (BF91021) which is 0.5 m thick. Above this tuff is 2 m of clays and conglomerate including a sliver of tuff 0.5 m thick which is highly altered (BF91022). Overlying this is a 1 m thick blue-gray tuff (BF91023), which is compositionally distinctive, and is named here the Kipcherere Tuff. It also crops out at the Ndau river fossil site. At Kipcherere it is overlain by about 7 m of cross bedded red gravels and silts, and is capped by a fine grained green tuff 1.5 m thick with small pumice clasts (BF925). There is a 12 m thick siltstone layer separating this tuff from an overlying fine grained dark grey tuff with small white spots (BF91024). This tuff is a good marker horizon that also crops out at Suteijun, north of Kipcherere and at Kibingor fossil sites (JM514, 1/996, 1/998), and is here named the Spotted Tuff. Above this tuff is 8 m of siltstones with sparse pebble clasts. These end abruptly at the base of a relatively thick (2 m) distinctive blue-gray tuff with root casts (BAR10526, BF91010, BF91011, BF-918) The tuff is coarse grained and consists almost solely of glass shards. Chemical analysis shows that this tuff correlates with the Lokochot Tuff in the Turkana Basin estimated to be about 3.5 Ma old (Feibel et al., 1989), and is referred to as the Lokochot Tuff in this work.

Above the Lokochot Tuff are 10 m of fossiliferous siltstones and conglomerates with fish bones. These are covered by a very light gray tuff (BF920; BF91012), 2 m thick, which, like the Lokochot Tuff, is also coarse grained and nearly pure volcanic glass. This tuff correlates with the Tulu Bor Tuff in the Turkana Basin, described by Cerling and Brown (1982). Feibel et al. (1989) estimated its age at 3.36 Ma. Above it is a thick layer (30 m) of silts and gravels (deltaic) which are capped by a brownish green partly altered

Figure 9. Stratigraphic sections of Kipcherere, Suteijun, and Kibingor fossil sites.


Thickness (m)
KIPCHERERE
SUTEIJUN
CHEMERON FM. AT KIBINGOR
120
100
80
60
40
20
0
BF91014
BF919
Tulu Bor Tuff
Lokochot Tuff
Spotted Tuff
BF925
Kipcherere Tuff
BF91022
BF91021
Suteijun Tuff
BF927
BF91016
Spotted Tuff
Kipcherere Tuff
BF936
KAPARAINA BASALT
KEY
Lava
Siltstone with pebbles
Siltstone
Diatomite
Tuff

tuff with a low glass content (BF919). From this layer to the top, an erosional surface, is 22 m of silt and gravel with a pumiceous tuff (BF91014) in the middle.

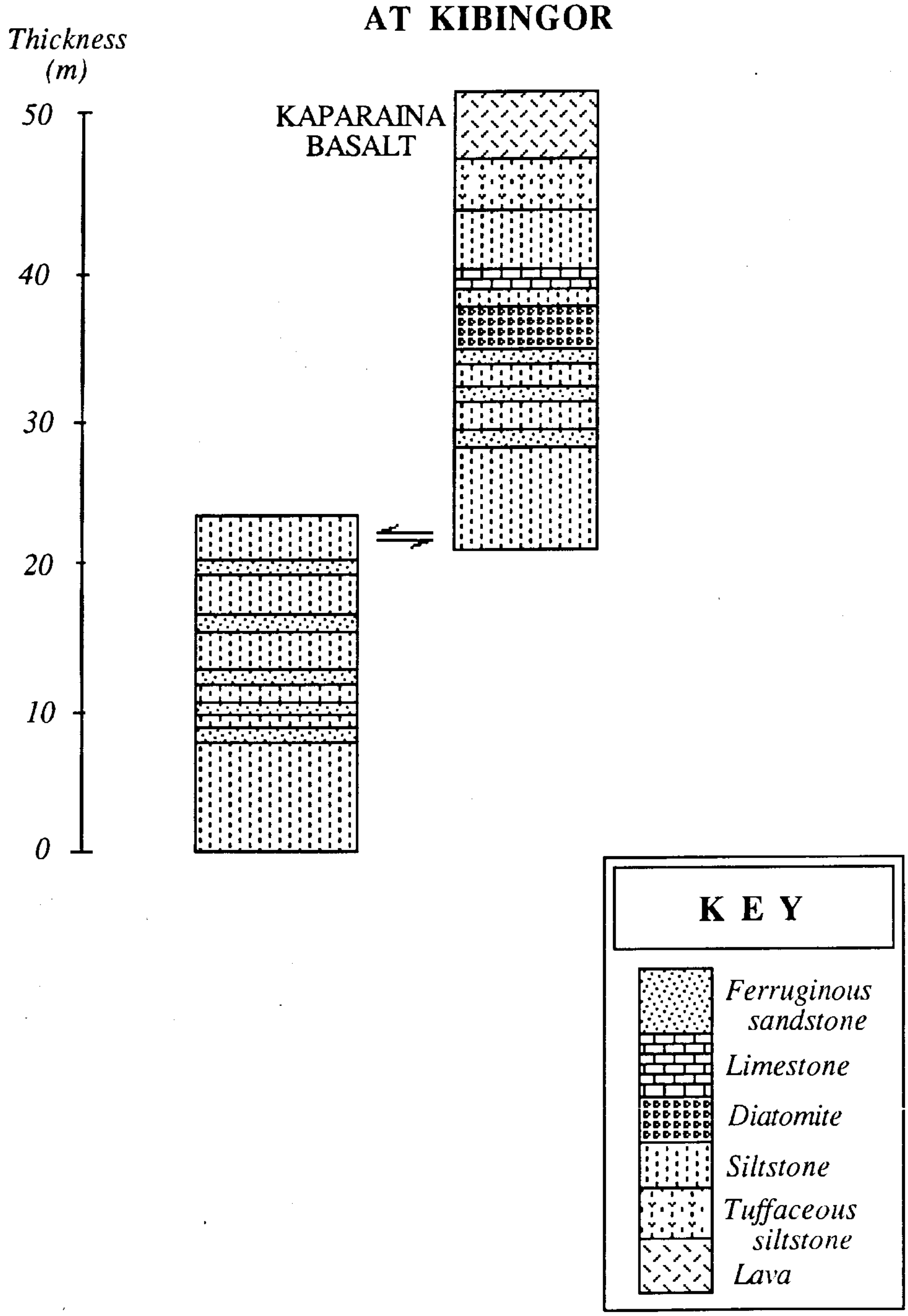
North of Kipcherere, a few miles closer to Suteijun, is another fossiliferous site whose location is marked **U** in Figure 3. Only about 50 m of section are exposed, consisting mainly of sparse outcrops of which only the bottom 10 m are continuous (Figure 9). Four tuffs are present, two of which correlate with the section at Kipcherere—the Spotted Tuff and the Lokochot Tuff. The tuffs at the bottom also correlate with other sections. The lowest tuff in the sequence (BF927) is brownish green, and correlates with a tuff (BF947) from the Chemeron River Section. The second tuff in the sequence is yellowish green (BF91008), and correlates with a tuff from Akai-Ititi, at Kanapoi about 300 km to the north. This tuff is named here the Suteijun Tuff. The Spotted Tuff lies higher in the sequence nearby, and the Lokochot Tuff is exposed still higher in the section about one kilometer to the west.

Fifteen km south of Kipcherere is a set of fossil sites (JM514, 1/996, 1/998), documented by the National Museums of Kenya. These are referred to collectively in this text as the Kibingor fossil sites located in the vicinty of the point marked **Y** on Figure 3. There is a stratigraphic problem in this area as apparently two formations are represented. One set of beds dips west and apparently extends below the Kaparaina Basalt. If this is the case, then these strata belong to the Lukeino Formation, which is defined as being immediately below the Kaparaina Basalt. Separated from these strata by a fault is another set of strata dipping east. Projecting the stratigraphic position of these beds places them above the Kaparaina basalt, making them part of the Chemeron Formation. Before this was realized early collectors of fossils may have mixed fossils from the two formations, ending up with fauna from two units of dissimilar age.

The author measured a section from beds attributed to the Lukeino Formation (Figure 10). Briefly, it is characterized by alternating layers of ferruginous conglomerates and siltstones. At the top is an enigmatic layer of diatomaceous tuffs with no glass.

Figure 10. Stratigraphic section of the Lukeino Formation at the Kibingor fossil sites.

SECTION OF THE LUKEINO FORMATION AT KIBINGOR

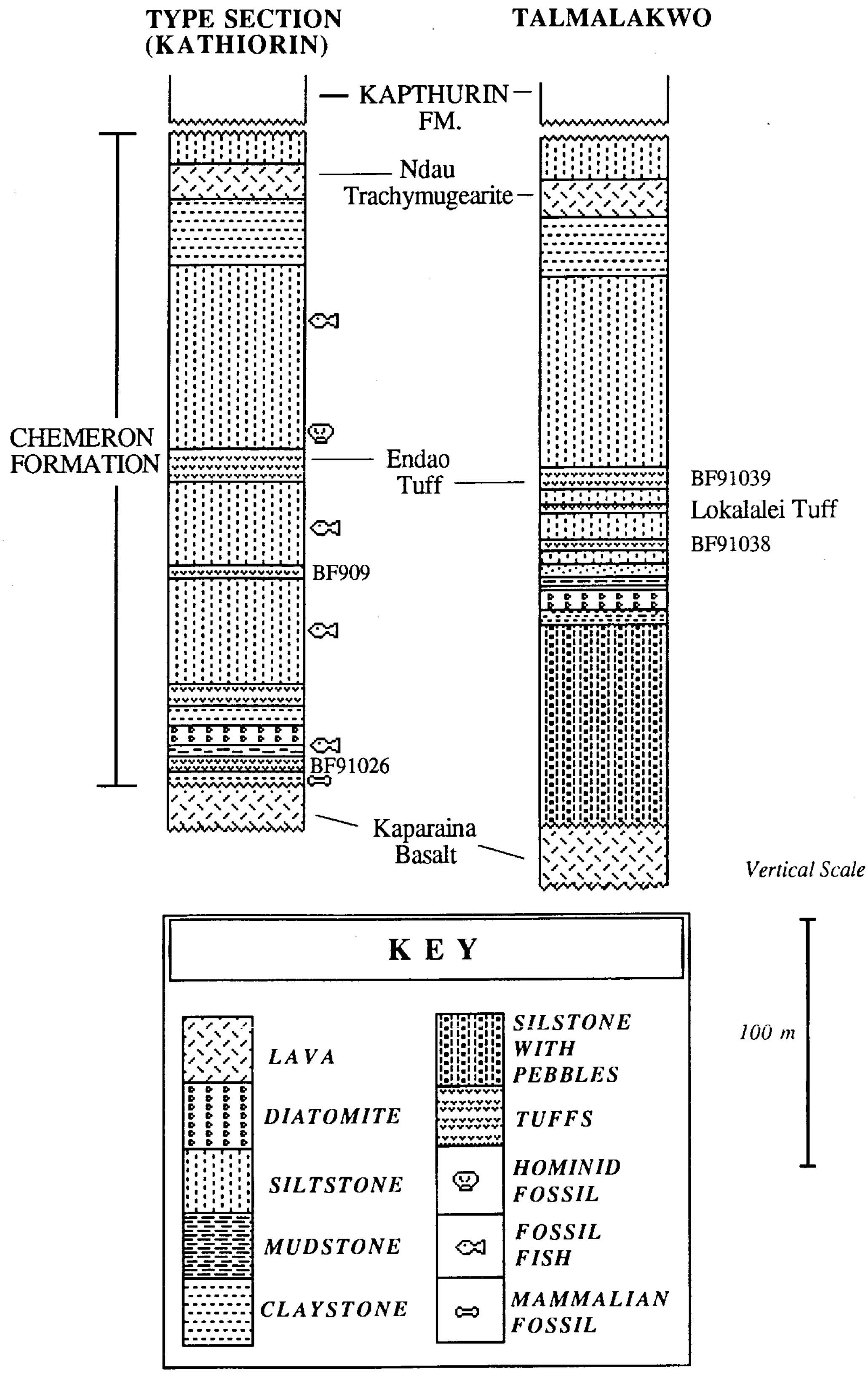


"Ghosts" of the shards seen under the microscope indicate that the glass is altered. The Chemeron Formation at the site is more straightforward (Figure 9). At the base is a diatomaceous tuff (BF936) similar to the one in the Lukeino Formation in which the glass is also highly altered. A small yield of glass (< 5%) allowed for analysis of the tuff by electron microprobe. Three additional tephra were investigated 1.5 km north of the site in a dry river valley. These are BF91020, a blue-gray tuff which lies below BF91019. BF91020 correlates with BF91017 and BF91018 a few hundred meters away, with BF941 in the Ndau River valley about three km to the south, and with BF91023, the Kipcherere Tuff. BF91019 is fine grained with white spots of feldspar and correlates with the Spotted Tuff at Kipcherere and Suteijun which is similar in character. Above BF91019 is a tuff (BF91016) with yellow-green glass shards. All these tephra layers are stratigraphically above the levels from which fossils were collected. Six km away, on the other side of the ridge, and separated from Kibingor by impenetrable bush, is the site of Talmalakwo.

Eight km northeast of Kibingor is the basal part of the "Type Section" of the Chemeron Formation of Martyn (1967). The section exposed close to site JM 90/91 (Figure 3) is what was described as the Basal Beds by Martyn (1967). In the type section (near the point marked **Z** on Figure 3) most of the beds dip eastwards and are highly faulted, but in the area described as the "Basal Beds," strata dip westwards which could result from faulting or folding. Faulting is quite apparent in the type section, but there is insufficient evidence to establish the extent of folding.

The lowest beds in this unit are generally argillaceous, and are best exposed in a tributary of the Kapthurin River. A section measured by the author (Figure 11) begins with a claystone layer (<10 m) rich in fossil fish overlain by a brown mudstone unit that varies in thickness up to 5 m. Within the claystone is a tuffaceous unit (BF91026) which has yielded glass intermediate in iron content between the bluish gray and the greenish tuffs. The brown mudstone is capped by a yellow clay, in turn overlain by a diatomite layer 8 m thick which is also exposed 200 m to the north, across the Kapthurin River. This

Figure 11. Stratigraphic sections of the Kapthurin (Type Section) and Talmalakwo sedimentary deposits.


TYPE SECTION
(KATHIORIN)
TALMALAKWO
KAPTHURIN FM.
Ndau
Trachymugearite
CHEMERON
FORMATION
Endao
Tuff
BF909
BF91026
Kaparaina
Basalt
BF91039
Lokalalei Tuff
BF91038
Vertical Scale
100 m
KEY
LAVA
DIATOMITE
SILTSTONE
MUDSTONE
CLAYSTONE
SILSTONE
WITH
PEBBLES
TUFFS
HOMINID
FOSSIL
FOSSIL
FISH
MAMMALIAN
FOSSIL

diatomite is overlain by about 5 m of brown claystone that contains a fishbed (0.5 m), and a tuff (BF-3, BF91027) at the top.

Downstream from this tributary, a series of faulted siltstones and conglomerates that Martyn (1967) described as the "Lower Fishbeds" are exposed along the Kapthurin River. Above the gravels the beds are lighter in color and made up of claystones or altered diatomites. Within these finer grained units are tuffs (BF91028, BF909) each less than 10 cm thick. The section is interrupted by a north-south fault immediately downstream.

The tuff which caps the lower fishbeds (BF91043) crops out discontinuously downstream immediately east of this fault. A few hundred meters farther downstream a layered tuff (BF14) about 4.5 m thick is exposed. Several samples were analyzed from this tuff, which show that it represents a single layer of tephra whose composition is the same as that of BF91043. This tuff also crops out in a tributary at site JM 85 (BF12). It is here named the Endao Tuff, for the general location of the area. Martyn himself described this tuff as the "Lower Tuffs." Dates on sanidines from this tuff at site JM85 average 2.41 Ma (Hill et al., 1992). Above this tuff is a series of siltstone beds rich in fish fossils, described by Martyn (1967) as the Upper Fishbeds. The thickness of this unit was estimated by Martyn (1967) to be 80 m, a value similar to that measured by the author.

Above the Upper Fish Beds is a gray, fine grained unit described by Martyn (1967) as the "Upper Tuffs." However, no evidence of volcanic glass was found in this unit. X-ray diffraction analysis of the material shows the unit to consist of Ca-beidellite, possibly devitrified ash. This bed lies immediately below the Ndau Trachymugearite, and is separated from it by a 40–60 cm layer brick-red baked horizon. The trachymugearite has well-developed cooling columns that can be also seen in the Barsemoi and Losegem river valleys (see McCall (1966) for a description of this unit).

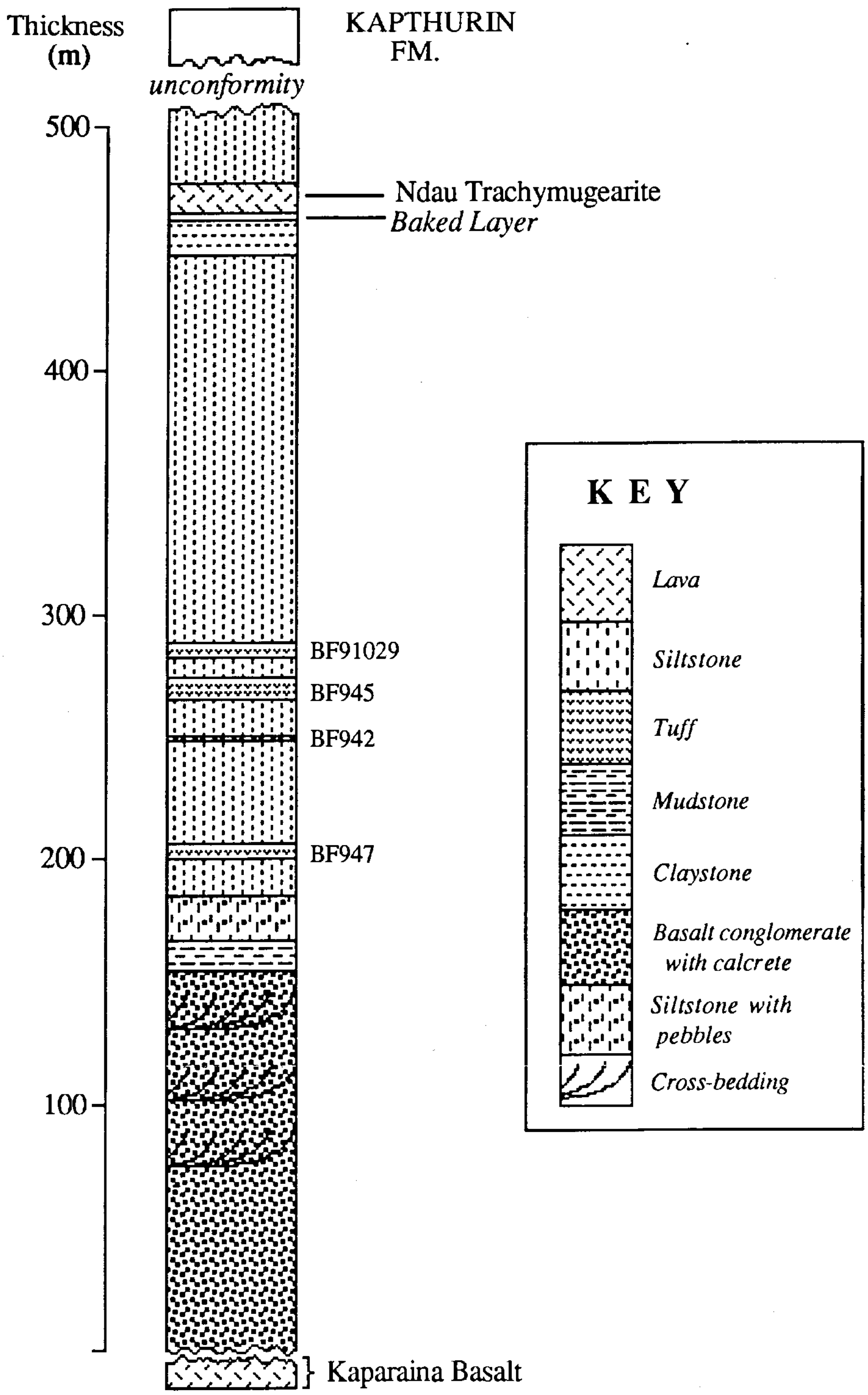
Five km west of Kapthurin is a section measured (Figure 11) by the author at Talmalakwo (near the point marked **X** in Figure 3), in a southern tributary of the Barsemoi River. The site is rich in mammalian bones (Rhinocerotidae, Hippopotamidae) at the base of the section. The lowest identifiable layer is a siltstone unit 6 m thick with a white claystone bed 6 cm thick at the base. Above the siltstone is a 1 m thick creamy white diatomite layer overlain by 4.5 m of siltstones and claystones with a 6 cm thick fishbed at the top. The dominant fish are *Clarias* and *Tilapia*. Immediately above the fishbed is a ripple marked buff sandstone about 0.5 m thick. The sandstone is overlain by about 10 m of siltstones which lie immediately below a distinctive thick diatomite bed that varies in color from orange to white. Two parallel faults about 100 m apart cut through the diatomite, and dip about 60 °E. In the center of the diatomite unit is a greenish yellow tuff (BF914, BF91038) that is chemically similar to BF91047, and to BF91028. Above the diatomite is 8–10 m of siltstone overlain by a fish bearing pebble conglomerate about 1.5 m thick. The fish bed is overlain by 4.5 m layer of siltstone followed by a bipartite tuff. The lower part of the tuff (BF9) is blue-gray, and correlates with Tuff D of the Shungura Formation and the Lokalalei Tuff in Nachukui Formation. The upper part (BF91039, BF915) is a ripple marked greenish tuff. The two tuffs must have erupted at nearly the same time as the two are in direct contact.

A siltstone 10–12 m thick overlies BF91039, which is followed by a thick (3.5 m) light grayish green tuffaceous layer (BF10, BF916). The bottom of the tuff is fissile, and the immediately underlying siltstones are rich in fossil fish bones. The tuff is made up of alternating layers of fine ash of lighter color, pumiceous layers, and dark green coarse ash. This unit correlates with BF12 from the JM85 site. Attempts to trace the stratigraphy above this point were fruitless. However, in the vicinity of the confluence of the Barsemoi and Ndau Rivers, the "Upper Tuffs" and the Ndau Trachymugearite are exposed. The Kapthurin and Talmalakwo sections span the "Type Section" of Martyn (1967).

Without describing the section along the Losegem River (west of the point marked **W** in Figure 3), the geology of the Chemeron Formation would be incomplete. Even though no fossils come from this locality, units are exposed that tie into the rest of the formation (Figure 12). High in this section is the Ndau Trachymugearite, with tuffaceous

Figure 12. Stratigraphic section of the Chemeron (Losegem) river valley deposits.

COMPOSITE SECTION OF THE CHEMERON FORMATION AT LOSEGEM



units and fish beds below it. The beds dip eastward at this locality, and the section is 500–550 m thick.

The bottom of the section is a thick succession of conglomerates, calcretes, siltstones, and gravels, with pebbles up to 3 cm diameter. Above this lowest unit are alternating siltstones and yellow and orange claystones with fossil fish. Intercalated with the claystones are basalt conglomerates with cobbles 1–10 cm in diameter. A mudstone (15 m thick) capped with a ferruginous conglomerate rich in fish fossils lies above the uppermost basalt conglomerate. Still higher are alternating siltstones and conglomerates (14 m), followed by a laminated siltstone (1 m) and a paper shale 75 cm thick. Above this is a 15 m thick gravel layer. This is capped by 7.5 m thick siltstone and a fissile, relatively fine grained tuff (BF947).

Above this unit is 50 m of section covered by thick soil and bush. It is highly faulted and capped with a conglomerate rich in fossil fish (BF942) above which is 16 m of silts and clays capped by a tuff (BF945). This tuff is chemically similar to, but not identical with, tuff BF925 at Kipcherere. Overlying this unit is about 11 m of siltstones capped by a tuff (BF91029) that appears grey in the field, but which has green shards. From XRF analysis it seems to correlate with BF91005 from Tabarin, but microprobe analysis indicates that glass shard populations has two modes, only one of which is related to BF91005. This possible correlation is hence not considered valid.

Downstream, the top of the Chemeron Formation is reached at the location where Walsh (1969) described his Nasagum section. It is similar in most respects to the top of the formation in the Ndau and Kapthurin River valleys. The significance of the Losegem River valley exposures is that they support the idea that the Chemeron Formation is a coherent unit.

TEPHRA FROM THE CHEMERON FORMATION

Fifteen tephra layers were identified in the Chemeron study. Although other beds in the Chemeron Formation also contain glass, only those layers with significant amounts of volcanic glass are discussed. Thicknesses of the tephra layers vary from a few cm to about 2 m, and most of the contacts of the tuffs are rather sharp. Some of the tuffs are known at only one locality, whereas others occur at many localities and are useful in establishing stratigraphic relations between sections. In some tephra layers the shard size varies from fine (<200 μm) to coarse, whereas others have consistently fine or coarse shards. Some of the tuffs contain pumice fragments and are composed of shards of more than one composition. In some cases the constituent populations are distinguishable microscopically as well as by electron microprobe.

The colors of the tuffs vary from very light gray (Tulu Bor Tuff), to blue-gray (Lokochot, Lokalalei and Kipcherere Tuffs) to various shades of green: yellow-green (BF91016, BF91038,BF919); greenish grey (Endao Tuff, BF91029), dark green (BF91006) and gray-green with whitish spots (the Spotted Tuff). The color is related to the iron content (see Table 1). As iron increases, colors appear in series roughly in the following order: light gray (Tulu Bor with 1.52% Fe_2O_3), blue-gray, gray, gray-green, green, yellow-green (BF 919 with 10.46% Fe_2O_3). In most cases the greenish tuffs are more altered than the gray tuffs, and very little glass remains in some of the altered tuffs. Even though bulk color is sometimes useful for distinguishing tephra, the same tephra layer may differ in color because of alteration—the more altered the tuff, the browner the bulk color. Only after relatively pure separates were obtained were the colors distinctive.

Sedimentary features of the tephra are important when considered together with features of associated beds. For example, tuffs BF3, and BF91039 contain ripple marks,

Table 1. Electron microprobe analyses of glass from tephra layers in the Baringo Basin

N	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Cl	Total
Endao Tuff												
Weighted Average		62.03	13.36	7.75	0.34	0.35	1.04	0.81	0.88	3.10	0.08	89.68
					Individual samples							
9	BAR10552 av	61.94	13.32	8.07	0.34	0.35	1.05	0.81	1.24	3.34	0.07	90.45
	Constituent modes											
2	BAR10552-1av	60.13	13.64	7.44	0.39	0.34	1.06	0.84	0.47	1.99	0.06	86.31
4	BAR10552-2av	61.82	13.33	7.95	0.36	0.34	1.06	0.81	1.33	3.31	0.07	90.32
3	BAR10552-3av	63.32	13.08	8.65	0.27	0.37	1.02	0.78	1.62	4.28	0.08	93.38
26	BF916 av	61.78	13.35	7.74	0.34	0.34	1.04	0.78	0.79	3.44	0.08	89.61
	Constituent modes											
3	BF916-1av	56.79	13.03	6.70	0.31	0.30	0.89	0.70	0.74	3.29	0.08	82.76
3	BF916-2av	61.97	13.73	7.20	0.40	0.33	1.08	0.90	0.36	2.44	0.08	88.40
12	BF916-3av	62.19	13.62	7.65	0.37	0.33	1.09	0.79	1.01	3.77	0.07	90.83
8	BF916-4av	62.98	12.92	8.47	0.29	0.37	1.01	0.75	0.64	3.36	0.09	90.79
4	BF91046 av	63.14	13.00	8.04	0.30	0.36	1.02	0.76	1.85	3.49	0.09	92.05
	Constituent modes											
2	BF91046-1av	61.73	12.72	7.56	0.32	0.32	1.00	0.76	0.44	2.29	0.09	87.22
2	BF91046-2av	64.55	13.28	8.52	0.27	0.40	1.03	0.77	3.27	4.68	0.09	96.87
Unnamed Tuff												
Weighted Average		61.81	12.56	8.92	0.16	0.34	1.12	0.68	0.88	2.95	0.10	89.46
					Individual samples							
29	BF915 av	61.74	12.63	8.99	0.17	0.34	1.14	0.68	0.87	3.09	0.10	89.65
	Constituent modes											
6	BF915-1av	61.13	13.38	8.21	0.22	0.32	1.25	0.70	1.05	3.65	0.07	89.92
23	BF915-2av	61.90	12.43	9.20	0.15	0.35	1.11	0.68	0.82	2.94	0.11	89.58
8	BF91039 av	62.07	12.32	8.68	0.14	0.35	1.04	0.68	0.93	2.45	0.10	88.76
	Constituent modes											
2	BF91039-1av	61.59	12.19	8.34	0.15	0.35	0.99	0.65	0.25	1.66	0.11	86.28
4	BF91039-2av	61.32	12.05	8.66	0.14	0.35	1.03	0.70	0.31	1.89	0.10	86.56
2	BF91039-3av	64.06	12.98	9.06	0.14	0.35	1.09	0.65	2.85	4.36	0.10	95.66
Lokalalei Tuff												
					Individual samples							
9	BF9 av	73.28	10.91	3.18	0.06	0.16	0.15	0.21	2.02	3.85	0.17	93.82
	Constituent modes											
7	BF9-1av	73.70	10.54	3.23	0.04	0.16	0.13	0.18	2.14	3.85	0.18	93.97
2	BF9-2av	71.82	12.23	3.00	0.13	0.16	0.21	0.30	1.58	3.83	0.14	93.26

Table 1 continued.

N	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Cl	Total
Unnamed Tuff												
	Weighted Average	60.30	12.61	9.33	0.30	0.35	0.90	0.67	0.70	1.91	0.21	87.12
					<u>**Individual samples**</u>							
27	BF914 av	60.70	12.77	9.44	0.30	0.35	0.90	0.66	0.83	2.10	0.21	88.06
	Constituent modes											
3	BF914-1av	59.52	13.34	8.56	0.30	0.32	0.90	0.62	0.79	2.09	0.16	86.44
21	BF914-2av	60.86	12.72	9.47	0.30	0.35	0.90	0.67	0.86	2.10	0.21	88.24
3	BF914-3av	60.72	12.56	10.15	0.30	0.34	0.90	0.65	0.68	2.11	0.24	88.40
8	BF91038 av	58.96	12.06	8.96	0.30	0.36	0.87	0.69	0.23	1.28	0.20	83.94
	Constituent modes											
5	BF91038-1av	59.16	12.25	8.54	0.30	0.33	0.88	0.67	0.23	1.29	0.19	83.87
3	BF91038-2av	58.63	11.76	9.66	0.30	0.41	0.86	0.72	0.22	1.27	0.22	84.05
Unnamed Tuff												
	Weighted Average	60.87	11.55	8.97	0.15	0.35	0.96	0.68	0.41	1.53	0.15	85.56
					<u>**Individual samples**</u>							
8	BF91047 av	60.48	11.68	8.53	0.16	0.34	1.00	0.68	0.42	1.44	0.15	84.90
	Constituent modes											
2	BF91047-2av	59.37	12.33	7.93	0.22	0.36	1.09	0.69	0.31	1.35	0.12	83.78
2	BF91047-3av	61.60	13.07	8.09	0.21	0.34	1.14	0.72	0.73	2.54	0.10	88.56
2	BF91047-1av	60.72	10.67	8.54	0.12	0.33	0.92	0.66	0.35	0.87	0.17	83.36
2	BF91047-4av	60.24	10.65	9.57	0.12	0.32	0.86	0.65	0.31	1.01	0.19	83.92
5	BF909 av	61.48	11.33	9.68	0.12	0.37	0.89	0.69	0.38	1.66	0.17	86.61
Unnamed Tuff												
	Weighted Average	61.46	13.38	7.58	0.22	0.33	0.84	0.59	0.47	1.12	0.13	85.98
					<u>**Individual samples**</u>							
10	BF3 av	61.48	13.27	7.62	0.22	0.33	0.84	0.59	0.46	1.12	0.14	85.93
	Constituent modes											
3	BF3-1av	59.66	12.98	7.05	0.21	0.32	0.82	0.54	0.54	1.28	0.13	83.40
2	BF3-2av	62.54	13.83	7.40	0.21	0.33	0.89	0.64	0.58	1.24	0.12	87.66
2	BF3-3av	62.03	13.02	7.87	0.22	0.34	0.85	0.57	0.44	1.03	0.14	86.37
3	BF3-4av	62.21	13.34	8.18	0.22	0.34	0.84	0.61	0.33	0.95	0.15	87.01
3	BF91027 av	61.42	13.74	7.44	0.23	0.31	0.84	0.61	0.47	1.09	0.13	86.16
Unnamed Tuff												
7	BF91026 av	61.87	13.36	5.94	0.15	0.27	0.88	0.50	0.38	1.23	0.18	84.79

Table 1 continued.

N	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Cl	Total
Unnamed Tuff												
Weighted Average		60.76	12.69	7.68	0.20	0.30	0.88	0.58	0.36	1.73	0.15	85.28
					Individual samples							
10	BF91014-1av	60.69	12.49	7.77	0.20	0.32	0.89	0.61	0.21	1.35	0.15	84.70
10	BF91025 av	60.83	12.89	7.60	0.19	0.29	0.88	0.55	0.52	2.12	0.15	85.87
	Constituent modes											
3	BF91025-1av	57.70	12.43	6.76	0.19	0.27	0.82	0.52	0.61	2.07	0.15	81.37
7	BF91025-2av	62.17	13.09	7.95	0.19	0.30	0.90	0.57	0.48	2.14	0.15	87.80
Unnamed Tuff												
Weighted Average		63.53	9.16	10.18	0.20	0.39	0.68	0.69	0.42	1.60	0.25	86.85
					Individual samples							
26	BF919 av	64.33	9.12	10.46	0.20	0.39	0.68	0.70	0.46	1.79	0.26	88.14
	Constituent modes											
24	BF919-1av	64.30	9.03	10.49	0.20	0.39	0.68	0.70	0.47	1.80	0.26	88.05
2	BF919-2av	64.70	10.30	10.05	0.24	0.39	0.75	0.66	0.42	1.66	0.23	89.18
15	BF91016 av	62.46	9.06	9.94	0.19	0.39	0.64	0.69	0.37	1.32	0.23	85.05
	Constituent modes											
2	BF91016-1av	63.13	9.94	9.37	0.20	0.34	0.69	0.73	0.44	1.48	0.20	86.32
5	BF91016-2av	62.13	9.24	9.69	0.20	0.41	0.66	0.68	0.34	1.28	0.23	84.63
8	BF91016-3av	62.49	8.72	10.24	0.18	0.39	0.62	0.69	0.36	1.30	0.25	85.00
Tulu Bor Tuff												
10	BF920-1av	74.03	12.05	1.52	0.05	0.05	0.30	0.12	2.66	3.71	0.09	94.50
Unnamed Tuff												
Weighted Average		61.94	12.99	7.09	0.21	0.32	0.66	0.54	0.52	2.68	0.20	86.95
					Individual samples							
9	BF91009 av	62.41	13.02	7.23	0.22	0.32	0.67	0.53	0.49	3.05	0.20	87.93
	Constituent modes											
2	BF91009-1av	61.89	13.02	7.06	0.22	0.33	0.67	0.54	0.40	2.86	0.19	86.99
7	BF91009-2av	62.56	13.02	7.28	0.21	0.31	0.66	0.53	0.51	3.10	0.21	88.19
8	BF91019 av	61.42	12.96	6.94	0.21	0.32	0.66	0.54	0.55	2.27	0.20	85.86
	Constituent modes											
2	BF91019-1av	60.48	12.91	6.75	0.19	0.30	0.64	0.53	0.41	2.02	0.20	84.23
6	BF91019-2av	61.73	12.98	7.00	0.21	0.32	0.67	0.54	0.60	2.36	0.20	86.40
Suteijun Tuff												
9	BF91008 av	68.70	7.61	7.94	0.00	0.22	0.28	0.22	0.06	1.06	0.48	86.57

Table 1 continued.

N	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Cl	Total
Unnamed Tuff												
17	BF925 av	59.87	14.44	8.19	0.19	0.32	1.01	0.52	0.30	2.64	0.19	87.49
	Constituent modes											
9	BF925a-1av	59.97	14.48	8.13	0.19	0.32	1.01	0.51	0.29	2.62	0.19	87.51
8	BF925b-1av	59.76	14.40	8.26	0.19	0.32	1.01	0.53	0.32	2.66	0.19	87.46
Kipcherere Tuff												
	Weighted Average	64.90	14.81	3.92	0.19	0.12	0.98	0.36	1.43	4.30	0.18	91.01
				Individual samples								
14	BF921 av	65.46	14.78	3.99	0.19	0.12	0.98	0.36	1.68	4.99	0.19	92.55
2	BF9411 av	64.18	15.08	4.17	0.19	0.15	1.04	0.43	0.69	3.63	0.16	89.55
8	BF91018 av	64.12	14.78	3.73	0.18	0.13	0.96	0.36	1.18	3.25	0.18	88.69
Unnamed Tuff												
23	BF923 av	56.99	18.10	6.60	0.24	0.31	0.86	0.30	0.48	3.08	0.25	86.95
	Constituent modes											
2	BF923-1av	57.46	18.15	6.09	0.22	0.29	1.06	0.33	0.40	2.95	0.22	86.93
21	BF923-2av	56.94	18.10	6.65	0.24	0.31	0.84	0.30	0.49	3.10	0.25	86.95
Unnamed Tuff												
	Weighted Average	58.88	14.82	7.19	0.20	0.29	0.98	0.46	1.39	3.18	0.19	87.40
				Individual samples								
6	BF91021r2 av	58.11	14.47	6.29	0.20	0.26	0.85	0.49	0.40	2.35	0.20	83.44
	Constituent modes											
2	BF91021r2-1av	57.61	14.93	5.64	0.21	0.23	0.88	0.50	0.38	2.39	0.17	82.78
2	BF91021r2-2av	58.61	14.02	6.95	0.19	0.29	0.82	0.47	0.42	2.32	0.22	84.10
2	BF91021r av	60.41	15.52	8.99	0.20	0.34	1.25	0.41	3.37	4.84	0.19	95.31
Tuff at Tabarin												
9	BF91006 av	67.42	8.76	7.84	0.01	0.25	0.37	0.24	0.25	1.34	0.24	86.46
	Constituent modes											
2	BF91006-1av	68.76	9.14	6.95	0.01	0.21	0.30	0.25	0.34	1.58	0.28	87.54
7	BF91006-2av	67.03	8.65	8.09	0.01	0.26	0.39	0.24	0.22	1.26	0.24	86.15
Tuff at Tabarin												
23	BF91005 av	64.00	9.12	8.54	0.10	0.34	0.59	0.59	0.15	1.87	0.26	85.29
	Constituent modes											
19	BF91005-1av	63.87	9.11	8.47	0.09	0.34	0.60	0.59	0.15	1.85	0.26	85.07
4	BF91005-2av	64.63	9.13	8.83	0.10	0.33	0.59	0.62	0.16	1.96	0.26	86.35
Unnamed Tuff												
9	BF91029 av	64.05	10.39	8.01	0.19	0.32	0.50	0.56	0.26	1.15	0.14	85.66
	Constituent modes											
4	BF91029-1av	63.20	11.16	7.24	0.23	0.28	0.52	0.54	0.33	1.32	0.11	85.07
5	BF91029-2av	64.73	9.78	8.62	0.15	0.36	0.49	0.56	0.20	1.02	0.15	86.12

Table 1 continued.

N	Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Cl	Total
Unnamed Tuff												
7	BF10551 av	66.59	12.59	4.96	0.00	0.15	0.68	0.31	0.99	2.38	0.17	88.67
	Constituent modes											
2	BAR10551-1av	68.68	11.42	4.58	0.00	0.13	0.38	0.22	0.96	2.44	0.23	88.82
5	BAR10551-2av	65.76	13.06	5.11	0.00	0.16	0.80	0.35	1.00	2.36	0.15	88.61
Unnamed Tuff												
Weighted Average		65.74	11.44	6.97	0.13	0.25	0.46	0.44	0.40	2.57	0.15	88.39
				Individual samples								
20	BF927 av	65.86	11.45	7.00	0.13	0.26	0.46	0.45	0.43	2.68	0.15	88.72
26	BF947 av	65.64	11.42	6.95	0.13	0.24	0.46	0.44	0.38	2.48	0.15	88.14
Unnamed Tuff												
14	BF945 av	60.40	11.49	9.89	0.13	0.35	0.89	0.66	0.42	2.64	0.17	86.88
	Constituent modes											
12	BF945-2av	60.44	11.38	9.97	0.13	0.36	0.87	0.67	0.44	2.72	0.17	86.97
2	BF945-1av	60.16	12.14	9.40	0.17	0.35	1.01	0.63	0.34	2.17	0.15	86.38
Unnamed Tuff												
9	BF936 av	61.62	14.96	6.06	0.07	0.24	1.30	0.32	0.47	2.12	0.14	87.15
Unnamed Tuff												
8	BF91022 av	58.86	15.06	8.15	0.18	0.32	1.11	0.46	1.73	3.28	0.20	89.15
	Constituent modes											
4	BF91022-1av	58.79	14.65	7.77	0.17	0.31	1.03	0.47	0.65	2.75	0.20	86.61
4	BF91022-2av	58.94	15.46	8.52	0.18	0.33	1.19	0.45	2.81	3.80	0.21	91.69

and are stratigraphically close to diatomites or laminated siltstones, so they may represent beaches or shallow water deposits. Some parts of the Endao Tuff are laminated, implying quiet waters. Root casts and leaf impressions in the Lokochot tuff at Kipcherere suggest that the area was subaerial following its deposition, and supported woody plant growth.

Shard morphology, although useful for characterizing tephra layers, was not important for correlation because it varies vertically in some tephra layers. For example, in one section the bottom (BF91046), has shards that are finer and lighter green than those at the top of the layer (BF91045) where the shards are coarser, partly pumiceous, and darker green. Two distinct shard shapes were noted in some tephra: pumiceous stretched shards (yellowish green) and bubble wall or platy shards (greenish). A corresponding dichotomy in the composition of the shards was clearly evident (see Table 1).

Glass content is higher in the gray tuffs, usually (80–90%) than in the greenish tuffs. The glass in many of the greenish tephra is significantly altered, possibly because their alkali (K and Na) content is (or originally was) higher than that of the gray tuffs. Alkali elements are easily exchanged during weathering, which may create inroads for even more weathering. Alternatively the higher iron content of the greenish tuffs may make them more susceptible to chemical alteration. However, iron rich samples from the Turkana Basin are not apparently more altered than those with less iron. Hydrologic environments experienced by the tephra may also play a role in the amount of alteration.

Apart from volcanic glass, the tuffs contain cogenetic minerals and detrital contaminants. Minerals noted include alkali-feldspar, quartz, plagioclase, pyroxene, amphibole, magnetite, ilmenite, zircon, sphene, and Fe-Ti oxides. Glass jackets on some minerals, especially feldspars but also pyroxenes, indicate that they are cogenetic. Microlites of feldspar are common in tephra with high iron content. Some of the tephra layers contain diatoms, the most common being *Melosira granulata* (identification by Dr. C. S. Feibel) implying that the tuffs were deposited in a freshwater lacustrine environment.

COMPOSITIONAL CHARACTERISTICS

Glasses from tephra layers in the Turkana Basin are hydrated, with the water content varying from 6 to 9% (Martz, 1979; Sarna-Wojcicki et al., 1985; Cerling et al., 1985; Haileab, 1988). Cerling et al. (1985) demonstrated that potassium and sodium were mobile, with the former being lost in the hydration process and the latter being lost or gained. Their principal point was that the analysis did not represent the original magmatic liquid composition. Because of postdepositional alteration, the alkalies were not used in considering probable correlations between samples. For example, potassium content varies greatly from sample to sample (see electron microprobe data on the Endao Tuff, Table 1), not because of lack of precision, but rather because the potassium content is actually variable.

Microprobe analysis was done for SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, TiO_2, Na_2O, K_2O, Cl, and F. For purposes of correlation the most useful components are Fe_2O_3, MgO, CaO, TiO_2, and Cl. Analysis was done on individual shards and averages were calculated after elimination of obviously anomalous analyses, keeping in mind the possibility of more than one shard population. Even within an individual tuff, the fluorine content was found to be very low and unreliable, and the potassium and sodium contents were imprecise. Sodium tends to evaporate under the electron beam, which leads to low values so that the analytical totals are normally 85–90%. Correlations were made using both microprobe analyses and XRF analyses independently. Abundances derived from the two techniques were not compared directly as the standards were not necessarily comparable. Also, no more than 30 glass shards were analyzed by electron microprobe whereas millions were analyzed in a bulk sample by XRF.

Major Elements

Silica and alumina content of the glasses is a good guide to the nature of the magmas that produced these tuffs. In the case of the Baringo tuffs the SiO_2 content varied from generally trachytic (<65%) to generally rhyolitic (>65%) composition. In fact a dimorphism is evident which could shed light on the source volcanoes. Trachytic magmas are less viscous than rhyolitic magmas, so it is likely that the source volcanoes of the trachytic tuffs were closer that those that produced the rhyolitic tuffs.

From electron microprobe data (Table 1) certain general trends were observed. The bluish gray tuffs (Lokalalei, Tulu Bor and Kipcherere) range from about 1.5 to just above 4.0% total iron expressed as Fe_2O_3. The greenish tuffs have much more iron, and range from about 7.0 to between 10.0 and 11.0% Fe_2O_3.

Apart from these two main groups, two tuffs are intermediate in total iron content, namely BF91026, with 5.94% Fe_2O_3 and BAR10551 with 4.96% Fe_2O_3. These two, however, differ in silica content and are not chemically identical. One other tuff with characteristics differing from most is BF91008, which, although displaying an iron content similar to the local tuffs, has a high percentage of silica (68.7%). It is interesting to note that it may correlate with tuff KP01-15-01 from Kanapoi, about 350 km northwest of Baringo. In this respect BF91008 is by no means a local tuff, but appears to be a widely dispersed unit.

Overall the greenish tuffs contain much more Ca than the blue-gray tuffs, which generally contain 0.18 to 0.32% CaO. In this respect the Kipcherere tuff differs from the blue gray tuffs because its CaO content is near 1.0%. It shares this characteristic with the greenish tuffs, for which the CaO varies from 0.62 to 1.36%, with the mode in the range 1.0 to 1.2%.

Minor and Trace Elements

These were mainly analysed by XRF methods, and results are shown in Table 2. First and foremost magnesium content appears to be lower in the tuffs known from both the Turkana Basin and Baringo, than in the majority of tuffs known from Baringo alone. It is noteworthy, however, that BAR10551 and BF91008 contain 0.05% MgO. TiO_2 values are quite consistent between different samples of an individual tuff, and therefore are useful for correlation. Total titanium contents (as TiO_2) range from 0.13 to 0.90%. Manganese too is fairly consistent between different samples of an individual tuff, and provides another minor element useful for correlation. MnO_2 content in these tephra ranges from 0.12 to 0.41%.

Barium content is rather low in most of the samples analyzed for this work, and does not differ much from one tephra layer to another, although it is useful for characterizing a few of the tephra. Niobium, yttrium, and zirconium are the most useful elements for purposes of correlation. It has been shown previously (Haileab, 1988) that Zr, Nb, and Y contents are tightly correlated with one another in individual tephra layers, but that the slopes and intercepts differ from one tephra layer to another. Rb is somewhat erratic, which is not surprising as it is an alkali metal, and Sr too is poorly behaved. Zinc ranges from 80 to 460 ppm, and is useful to confirm correlations made on the basis of the other elements, but the values are not as tightly grouped as those on other trace elements.

Table 2. X-ray fluorescence analyses of glass separates from tephra layers in the Baringo Basin and correlative tephra from elsewhere.

Sample	Ba	Mg	Mn	Nb	Rb	Sr	Ti	Y	Zn	Zr	Location
Endao Tuff											
BAR10552	40	0.29	2736	152	98	29	5300	63	196	619	Kapthurin
BF12	37	0.18	2744	152	98	4	5052	63	188	627	Kapthurin
BF91043	62	0.18	2787	148	94	11	5212	59	195	592	Kapthurin
BF10	40		2830	141	82	1	4669	67	181	564	Talmalakwo
BF91045	34	0.13	2851	147	93	3	5280	62	192	607	Kapthurin
BF14A	64	0.21	2861	142	91	6	5324	61	199	585	Kapthurin
BF916	38	0.18	2882	142	96	7	5367	59	205	600	Kapthurin
BF91044	42	0.15	2907	143	93	4	5288	60	191	584	Kapthurin
BF91046	60	0.14	3125	149	90	20	5361	60	194	603	Kapthurin
Unnamed Tuff											
BAR10551	131	0.02	1121	141	134	13	2223	82	181	848	
Unnamed Tuff											
BF91039	53	0.07	2910	173	95	25	4775	75	222	708	Talmalakwo
Lokalalei Tuff											
BF9	18	0.06	1240	172	161	2	1602	86	171	1270	Talmalakwo
BF9R	65	0.10	1180	153	152	4	2107	76	152	1102	Talmalakwo
Tuff D	44	0.10	1072	153	147	1	1922	75	222	708	Shungura
Unnamed Tuff											
BF91038	75	0.13	2911	199	93	42	4778	81	221	833	Talmalakwo
BF91028	117	0.13	2489	191	88	13	5078	84	212	856	Kapthurin
BF91047	78	0.08	2711	206	91	71	5072	89	228	904	Kapthurin
BF909	79	0.08	2804	211	95	64	4966	90	244	936	Kapthurin
Unnamed Tuff											
BF91027	86	0.10	2936	272	102	73	4446	94	267	1092	Kapthurin Trib.
BF3	336	0.25	3275	271	97	317	4604	89	351	1017	Kapthurin Trib.
Unnamed Tuff											
BF91026	182	0.10	2179	270	114	26	3720	80	198	933	Kapthurin Trib.
Unnamed Tuff											
BF91025	70	0.08	2737	199	128	15	4100	68	179	820	Kipcherere
BF91014	122	0.11	3088	200	131	32	4164	67	181	828	Kipcherere
Unnamed Tuff											
BF919	92	0.13	2629	387	159	95	5302	170	332	1810	Kipcherere
BF91016	159	0.09	3140	378	93	111	4903	161	362	1910	Kibingor
Tulu Bor Tuff											
BF920	200	0.04	430	89	138	10	894	57	86	417	Kipcherere
BF91012	172	0.03	431	92	135	7	880	56	82	400	Kipcherere
ETH133	199		400	81	124	14	1232	65	60	388	Shungura

Table 2 continued.

Sample	Ba	Mg	Mn	Nb	Rb	Sr	Ti	Y	Zn	Zr	Location
Lokochot Tuff											
K80-295	153	0.02	845	163	144	5	1273	132	248	1450	Koobi Fora
BAR10526FN	137	0.01	860	159	158	5	1237	133	251	1432	Kipcherere
Tuff A'81	143	0.02	887	167	149	10	1329	139	262	1500	Shungura
BF918	148	0.03	903	166	162	7	1351	140	263	1505	Kipcherere
BAR10526	150	0.03	980	165	157	10	1329	138	270	1491	Kipcherere
BF91011	107	0.01	1042	184	180	2	1434	157	306	1700	Suteijun
Spotted Tuff											
BF91024	45	0.13	2450	282	158	4	3699	87	239	1072	Kipcherere
BF91019	69	0.12	2483	285	134	14	3772	82	242	1110	Kibingor
BF91009	31	0.17	2583	276	165	6	3799	87	242	1078	Suteijun
Suteijun Tuff											
KP01-15-01	31	0.02	1961	458	302	23	1800	226	438	2333	Kanapoi
BF91008	34	0.01	2017	479	206	7	1701	233	460	2493	Suteijun
Unnamed tuff											
BF91029	55	0.10	2854	333	105	16	4063	133	384	1745	Losegem
Unnamed Tuff											
BF925	21	0.10	2588	293	212	5	3600	108	249	1216	Kipcherere
Unnamed Tuff											
BF945	45	0.08	2952	220	120	5	4728	105	275	1010	Losegem
Kipcherere Tuff											
BF921	166	0.12	964	180	208	26	2738	82	130	1160	Kipcherere
BF91023R	136	0.10	978	178	196	18	2434	82	130	1169	Kipcherere
BF91018	169	0.12	990	179	186	27	2566	81	133	1174	Kibingor
BF924	134	0.11	1007	181	217	17	2516	84	134	1173	Kipcherere
BF91020	145	0.11	1010	183	189	19	2534	82	132	1195	Kibingor
BF91023R2	133	0.09	1019	175	193	16	2542	81	136	1134	Kipcherere
BF941	178	0.12	1081	181	196	23	2529	83	135	1194	Kibingor
BF91017	417	0.12	2244	182	188	20	2545	82	133	1190	Kibingor
Unnamed Tuff											
BF923	102	0.19	2465	302	235	42	2409	99	217	1101	Kipcherere
Unnamed Tuff											
BF91021R2	354	0.17	2162	251	148	32	3421	69	195	947	Kipcherere
Unnamed Tuff											
BF91002	55	0.10	2755	211	134	5	3957	84	227	1034	Tabarin
Unnamed Tuff											
BF91006	79	0.02	2088	247	179	26	2068	142	298	1412	Tabarin
Unnamed Tuff											
BF91005	35	0.06	2888	369	226	9	4115	146	343	1790	Tabarin

TEPHRA CORRELATIONS

Correlation of tephra units was made on the basis of chemical composition, and the local correlations established in this way were used as a guide to stratigraphic placement where faults complicated the section. The various tephra were sorted for a minor or trace element (e.g., strontium), and sets which were mutually close were considered for the next step which was a repeat of the same process for a different element. If consistency in range was observed after five or six steps, then inferred stratigraphic placement was used for confirmation of the chemical correlation. If stratigraphic positions differed significantly, then the mutual sets were considered to be chemically related but not correlative.

Three tephra layers correlate with tephra layers from the Omo Group exposed in the Turkana Basin of northern Kenya and southwestern Ethiopia, and a fourth correlates with a tuff exposed at Kanapoi in the Kerio River valley in the southwestern part of the Turkana Basin. Other correlations have been established between local sections of the Chemeron Formation itself, but the tephra on which these are based have not yet been found elsewhere. These are treated in sequence from oldest to youngest below.

The sections at Kipcherere and at Kibingor are securely linked by a tuff for which eight analyses are available (Table 2; Kipcherere Tuff). One of these analyses is discrepant (BF91017) in two elements—Ba and Mn. This discrepancy may result from a very small amount of contamination by psilomelane ($BaMn_9O_{16}(OH)_4$), because the ratio Ba to Mn is the same in psilomelane as in the excess of these elements in the analysis. Even discounting this sample, there is little doubt that the two sections can be linked at this level. Of all the tephra this is the most useful stratigraphic marker within the Chemeron Formation, and extends from Kipcherere 12 km southward to Kibingor.

A tuff (BF91008) in the North Kipcherere section correlates with a tuff from Akai-Ititi at Kanapoi (Powers, 1980; see Table 2). Powers (1980, p. A-12) describes this unit as a light whitish yellow, silty tuff with climbing ripple drift through much of the unit. He adds that the ripple drifts climb toward N20 °E, and that the unit is 6 m thick and prominent throughout Kanapoi. The correlative tuff in Baringo has been named the Suteijun Tuff.

Above the Suteijun Tuff is a distinctive tephra unit named the Spotted Tuff. Locally it is quite useful, for it is found in three sections—Suteijun, Kipcherere, and Kibingor. This tephra layer has unique field characteristics making it useful as a marker bed—it is fine grained with distinctive white spots formed by pumice lapilli. Analyses of the Spotted Tuff are given in Table 2, where it is seen that the chemical composition of samples BF91019, from Kibingor, BF91009 from Suteijun, and BF91024 from Kipcherere are nearly identical. It is likely that this tuff will prove useful for correlation to other localities within the Baringo basin.

The oldest tuff in the Chemeron Formation that correlates with the Omo Group is the Lokochot Tuff. It correlates with the Lokochot Tuff from the Turkana Basin described by Cerling and Brown (1982). In the Chemeron Formation the Lokochot Tuff is exposed at Kipcherere (BF918), and also at Suteijun (BF91010). The Lokochot Tuff of the Koobi Fora and Nachukui Formations is equivalent to Tuff A of the Shungura Formation. It has also been identified in the Lake Albert Basin in Uganda (Pickford et al., 1991), and in deep sea cores from the Gulf of Aden (Sarna-Wojcicki et al., 1985; Brown et al., 1992). The bracketing ages in Baringo, older than 2 Ma and younger than 5 Ma is consistent with its estimated age of 3.5 Ma (Feibel et al., 1989).

At Kipcherere about 10 m above the Lokochot Tuff is a tuff that correlates with the β-Tulu Bor Tuff of the Turkana Basin (see Tables 1 and 2) and is referred to by the same name in the Baringo Basin. This tuff is equivalent to Tuff B-β of the Shungura Formation, and has also been identified in the Nachukui Formation (Harris et al., 1988). Brown (1982) correlated the β-Tulu Bor Tuff with the Sidi Hakoma Tuff of the Hadar Formation in Ethiopia, and Sarna-Wojcicki et al. (1985) identified it in deep sea cores in the Gulf of Aden. The position of the β-Tulu Bor Tuff above the Lokochot Tuff in the Baringo Basin lends additional support to the correlation of both of these units.

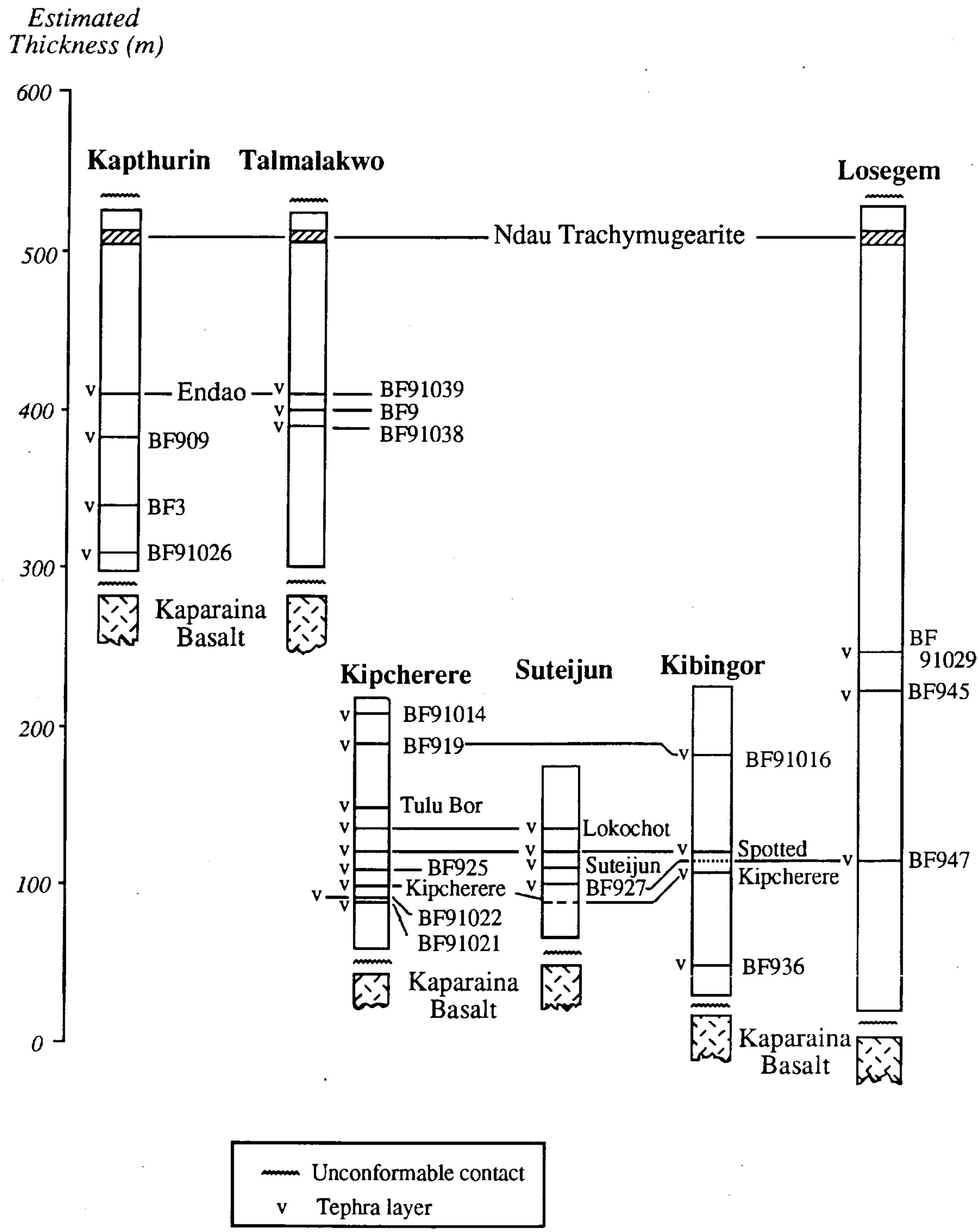
The next pair of local tuffs that correlate is BF909 (Kapthurin River) and BF91047. BF91047 lies in the center of a diatomite below BF91046, the Endao Tuff. This correlation was made on the basis of XRF data; microprobe analyses were not very useful, perhaps because only 10 grains were analyzed. This tuff occurs in a diatomite south of the Kapthurin River, but in a white claystone along the river itself.

Above the diatomite layer at Talmalakwo is a thin blue-gray tuff (BF9) that correlates with the Lokalalei Tuff of the Nachukui and Koobi Fora Formations in the Turkana Basin, and with Tuff D of the Shungura Formation (see Tables 1 and 2).

At Talmalakwo, the Endao Tuff lies 5 m above the Lokalalei Tuff, and it is also exposed in the Type Section of the Chemeron Formation of Martyn (1969). This tuff underlies site JM85 in the Kapthurin River section where a hominid temporal fragment (a surface discovery) was found. Hill et al. (1992) have dated the Endao Tuff at 2.43 Ma by the $^{40}Ar/^{39}Ar$ single crystal laser fusion technique. Feibel et al. (1989) dated the Lokalalei tuff at 2.52 Ma by K-Ar techniques, so the dates are in agreement with the observed stratigraphic order. Seven analyses of the Endao Tuff are given in Table 2. Samples from the top (BF91045) to the bottom (BF91046) are nearly identical in composition, indicating that the tuff is homogeneous. Titanium is very abundant (ca 5300 ppm), as is Mn (ca. 2800 ppm). This is the most extensive tuff in the "Type Section" and is observed in the Kapthurin River valley and southward beyond the Barsemoi River to the tributary at Talmalakwo.

Correlations of tephra from the Chemeron Formation with tephra from within the formation and from elsewhere are summarized in Tables 1 and 2, where the correlative tephra are placed in clusters. The inferred stratigraphic positions are displayed in Figure 13 and establish stratigraphic and temporal controls for the Chemeron Formation.

Figure 13. Stratigraphic order of analyzed tephra in the Chemeron Formation.



Estimated Thickness (m)
600
500
400
300
200
100
0
Kapthurin
Talmalakwo
Losegem
Ndau Trachymugearite
Endao
BF909
BF3
BF91026
BF91039
BF9
BF91038
Kaparaina Basalt
Kipcherere
Suteijun
Kibingor
BF 91029
BF945
BF91014
BF919
BF91016
Tulu Bor
Lokochot
Spotted
Kipcherere
BF947
BF925
Kipcherere
Suteijun
BF927
BF91022
BF91021
BF936
Kaparaina Basalt
Kaparaina Basalt
Unconformable contact
v Tephra layer

IMPLICATIONS OF CORRELATIONS ON CHRONOLOGY, STRATIGRAPHY, AND PALEONTOLOGY

From this study more stratigraphic and temporal controls on the Chemeron Formation have emerged. The lack of control from previous data is emphasized in Hill et al. (1986) where a question mark is placed on their diagram representing the stratigraphy of the Chemeron Formation. This section of the thesis updates the controls with the new data available from this study, but earlier data are also utilized.

The lowest control is the Kaparaina Basalt. Hill et al. (1986) indicate that the top of this unit ranges from 5.14 to 5.9 Ma in age. The 5.14 Ma date is derived from whole rock material from the top of the unit. Three dates on feldspar are all 5.65 Ma, even though they were obtained from anorthoclase and plagioclase concentrates. However, another plagioclase date gives 5.9 Ma for the basalts. All these dates may be correct because at the Ndau River near Kibingor the Kaparaina Basalt is not a single lava flow, but a suite of flows. Dagley et al. (1978) show that nearly all the Kaparaina Basalt flows are reversed, thus placing them in the reversed polarity interval from 5.1–5.7 Ma (Harland et al., 1989, p. 148). Considering that the whole rock K-Ar ages may be anomalously low, and noting that the basalt is heavily weathered at the top, the beds immediately overlying the basalts are not likely to be older than 5.5 Ma.

Complications arise when it comes to defining an age for the base of the Chemeron Formation. Earlier workers (e.g., Martyn, 1967) treated observed contacts between the beds in the Chemeron and the Kaparaina Basalt as the base of the formation. This proved confusing as the stratigraphic position of the beds varies depending on the location. The contact of the basalt and the sedimentary beds of the formation is evidently a disconformity.

Depending on prevailing hydrographic conditions and tectonics, the position of proto-Lake Baringo and other associated water bodies was not fixed through Plio-Pleistocene time. Indeed, at certain times there may have been no lake at all. Because of this, the age of the basal beds of the Chemeron Formation may vary from one place to another. Hence the "Basal Beds" of Martyn (1967), later referred to by Bishop et al. (1971) as the Basal Member of the Chemeron Formation, defined in the type section, rest on the disconformity but are not the oldest sedimentary beds above the Kaparaina Basalt. In the vicinity of the "Basal Beds," it is likely that the sediments immediately above the Kaparaina Basalt are considerably younger than 3.36 Ma because they contain neither the Lokochot nor Tulu Bor Tuffs. The tuffs present nearest the base (BF3 and BF91026) are not yet known in any other section in the basin. In previous attempts to date the Chemeron Formation glass from "tuffs from above the Kaparaina Basalt" yielded ages of 2.78 Ma and 5.4 Ma (Hill et al., 1986). The discrepancy may arise either from anomalous potassium values or sampling in the vicinity of the "Basal Beds," but neither date can be relied upon.

The oldest reported dates from the Chemeron Formation are those on the Cheseton Lapilli Tuff reported in Pickford et al. (1984). The ages, 5.06 Ma for whole rock and 5.1 Ma for anorthoclase, overlap with the 5.25 Ma age reported by Hill (1985) for a tuff from Tabarin. From Tabarin Hill (1985) reports dates of 5.25 ± 0.04 Ma (on sanidine) and 4.96 ± 0.03 Ma (on anorthoclase) from a tuff.

Above Tabarin, the next set of temporal controls is at Kipcherere. At this section a tuff correlated with the Lokochot Tuff (3.5 Ma; Feibel et al., 1989) is separated by ten meters of sediments from the Tulu Bor Tuff (3.36 Ma; Feibel et al., 1989). Assuming minimum sedimentation between these two tephra layers, the upper part of the section would span at least 1.6 Ma as it is 120 m thick. If this holds for the lower part of the section, the base would be approximately 4.3 Ma old.

The other tephra layers from Kipcherere are not dated, but two layers identified below the Lokochot Tuff in the Kipcherere area, correlate with similar ones from the

Kibingor fossil sites. The fossil sites at Kibingor occur well below the correlatives of the tuffs at Kipcherere. The lower tuffs at Kipcherere are themselves considerably older than the Lokochot Tuff, probably on the order of 4 Ma in age. On this basis, most of the fossil beds from Chemeron Formation at the Kibingor fossil sites are likely older than 4 Ma, but younger than 5.65 Ma.

Finally in the "Type Section" the lowest dated tuff is the Lokalalei Tuff (2.52 Ma; Feibel et al., 1989). The tuff is an upper age limit for the "Basal Beds" of Martyn (1967). It is separated by 15 m of sediments from the Endao Tuff at Talmalakwo. Samples from site JM85 have yielded dates averaging 2.41 ± 0.02 Ma (Hill et al., 1992). Above the Endao Tuff the next temporal control is the Songoiwa Trachymugearite, dated at 2.13 Ma (Hill et al., 1986) after recalculating the original date of Chapman and Brook (1978). This unit, however, is present only in the Songoiwa area and is not widespread in the region. Near the "Type Section," the beds continue upward to the Ndau Trachymugearite, whose age is reported as 1.57 Ma by Hill et al. (1986). From the beds immediately above the Ndau Trachymugearite to the top of the formation, no dates are available. The top of the formation is an angular nonconformity, so the age of the top of the Chemeron Formation varies from place to place.

Figure 13 gives the stratigraphic order of the tephra layers in the Chemeron Formation. As there are no correlative tephra to tie together the Type Area and Kipcherere, the beds in the two basins may have been deposited at different times.

Geochemical correlation of tephra utilizing major, minor and trace elements analysis has been very successful in resolving stratigraphic problems in the Turkana Basin. This is evident in the work by Cerling et al. (1979), Cerling and Brown (1982), and Brown and Cerling (1982), which helped resolve the prevailing stratigraphic "quagmire" in the Koobi Fora Formation and also established strong correlation between strata in the Koobi Fora Formation and those in the Shungura Formation in the Omo River Valley. The usefulness of the technique in long-distance correlation is evident in the work of Sarna-Wojcicki et al.

(1985), where tuffs from the Turkana Basin were observed in deep sea drilling cores in the Gulf of Aden. The method was the major technique used by Brown and Feibel (1986) in the revision of the stratigraphy of the Koobi Fora Formation, and Harris et al. (1988) in establishing the stratigraphy of the Nachukui Formation, a hominid-bearing formation west of Lake Turkana. With the above factors in mind this technique was applied to resolve some of the controversies in Baringo.

In the Chemeron Formation most of the fossils were evidently found on the surface. This implies that the stratigraphic level where a fossil was found can only be considered to be a lower bound. It is also notable that at most sites material from only one stratigraphic position (usually a tuff) was dated. Without bracketing controls complications are likely to occur when trying to estimate the age of a fossil.

From this study one section (Kipcherere) is suggested to represent a minimum age range of 1.6 Ma. This implies that most stratigraphic sections more than 100 m thick in the Chemeron Formation could span an age range greater or equal to 1.5 Ma. Hence without stratigraphic placement it is difficult to assign an age to a fossil of interest using other fossils to this end. A case in point is the use of *Anancus* to suggest an age for the hominid at Tabarin (see Hill, 1985) where the Last Appearance Datum for *Anancus* is reported to be 4.2 Ma. The distribution of *Anancus* in the section is not stated, so it is difficult to estimate an age for the hominid fossil on this basis, especially because the stratigraphic position of the hominid too is indeterminate.

A similar situation is observed when one considers most of the recent fossil material from the Chemeron Formation. In the case of earlier material (Martyn, 1969) stratigraphic positions for *Papio baringesis*, *Paracolobus chemeroni* and the hominid temporal reported by Hill et al. (1992) to be *Homo* are specified. Other fossils (e.g., from Kipcherere and Kibingor) are documented but not stratigraphically placed. Given that the Chemeron Formation may span as much as 4 million years, the faunal lists alone are not very helpful in establishing ages.

Information on stratigraphic placement is critical when using faunal evidence to deduce the age of a critical fossil. Cooke (1985) utilized the faunal ranges of suids in setting a chronological time scale for the Plio-Pleistocene. The suids feature prominently in the Chemeron Formation, as is evident at Tabarin (Hill, 1985), where *Nyanzachoerus jaegeri* was used to help place an australopithecine mandible chronologically. The age of the mandible was suggested to be "not considerably younger than 5 Ma," but the Last Appearance Datum for this suid is about 3.6 Ma. Also, recent revisions of the age of the Cindery Tuff (Haileab and Brown, 1992) lowers the age range of *Enhydrion* cf. *campani* to as young as 3.8 Ma. As the temporal range of various fossil taxa become better known, revision may be required on the assigned ages many species from Baringo. The age of the fossils from the "Basal Beds" does not seem to be a problem; these fall in the range 2.6–3.0 Ma resolving finally the controversy over the "Basal Beds."

DISCUSSION AND CONCLUSION

New data from this study on the composition of glass separates from tephra in the Chemeron Formation establish new temporal control for the formation. It is probable that poor delineation could have led to fauna from the younger part of Lukeino Formation being lumped with that from the "Basal Member" of the Chemeron Formation. As the use of the term "Basal Member" becomes more and more vague, it causes continued confusion, so it is recommended that use of this term be discontinued. New stratigraphic controls have been established in the Chemeron Formation. As some of these are also good temporal controls, the stratigraphy of the Chemeron Formation is now fairly clear.

Strata in the Kipcherere depositional basin are mostly older than those in the "Type Area," and include both the Lokochot and Tulu Bor Tuffs. The Lokochot Tuff is known to be quite widespread, as it is present in the Indian Ocean (Sarna-Wojcicki et al., 1985). The presence of this tuff and the Tulu Bor Tuff in other localities (Haileab, 1988; Brown et al., 1992) relates to the magnitude of the associated volcanic eruptions. Pickford et al. (1991) report the Lokochot Tuff in the Lake Albert Basin, in the Western Rift Valley. The known distribution suggests that monsoon winds may have been responsible for aeolian dispersal.

The Lokalalei Tuff (BF-9), which occurs only as a thin sliver 2–3 cm thick is also of substantial importance, for it provides an older age limit for the Basal Beds of Martyn (1967). The paleontology of the Chemeron Formation ought to be re-examined in view of the new findings, and the stratigraphic control on new collections ought to be more firmly established.

Last but not least this study establishes the importance of tephra in long distance correlation studies in East Africa.

APPENDIX

COMPOSITIONAL CHARACTERISTICS

Sample	Si	Al	Fe	Mg	Ca	Na	K	Mn	Nb	Rb	Sr	Ti	Y	Zn	Zr
CMN 3	35.05	5.03	3.85	0.012	0.24	4.07	3.64	0.1106	0.0238	0.0224	0.0003	0.2073	0.0126	0.0227	0.1291
G-2	33.41	8.15	1.85	0.458	1.39	3.02	3.74	0.0260	0.0013	0.0168	0.0479	0.2780	0.0012	0.0085	0.0300
GSP-1	32.58	8.07	3.03	0.579	1.44	2.08	4.59	0.0331	0.0029	0.0254	0.0233	0.3990	0.0030	0.0098	0.0500
Mer 1	33.70	7.20	2.33	0.223	0.60	3.78	4.20	0.1042	0.0271	0.0210	0.0059	0.3218	0.0082	0.0131	0.1147
Mer 3	33.99	4.23	5.21	0.018	0.23	4.65	3.48	0.1597	0.0421	0.0359	0.0005	0.1766	0.0256	0.0415	0.2756
Mer 4	34.23	4.23	5.37	0.012	0.21	4.93	3.46	0.1617	0.0475	0.0396	0.0009	0.1775	0.0292	0.0445	0.3092
Mer 5	34.33	4.07	6.04	0.018	0.26	4.96	3.46	0.1956	0.0270	0.0230	0.0006	0.1816	0.0167	0.0348	0.1304
Mer 6	34.47	4.82	4.90	0.018	0.24	4.56	3.52	0.1468	0.0243	0.0242	0.0001	0.1925	0.0148	0.0297	0.1562
Mer 9	35.25	5.50	2.64	0.012	0.10	4.05	3.54	0.0411	0.0335	0.0388	0.0001	0.1032	0.0186	0.0263	0.1760
Mer 13	33.94	4.34	5.85	0.024	0.28	5.00	3.44	0.1880	0.0329	0.0198	0.0001	0.1954	0.0206	0.0350	0.1641
Mer 15	30.70	6.88	6.36	0.217	0.97	4.87	3.94	0.2370	0.0225	0.0137	0.0005	0.5079	0.0089	0.0200	0.0961
Mer 24	33.70	3.76	5.74	0.006	0.14	5.57	3.24	0.1880	0.0539	0.0401	0.0002	0.1617	0.0327	0.0509	0.2988
Mer 34	35.78	5.66	2.64	0.024	0.22	4.07	3.49	0.0454	0.0312	0.0370	0.0008	0.1400	0.0162	0.0244	0.1489
Mer 36	25.48	7.36	6.83	0.139	0.71	9.64	3.48	0.4183	0.0522	0.0228	0.0025	0.2248	0.0203	0.0387	0.1905
Mer 51	30.12	6.19	5.77	0.259	0.47	5.92	3.79	0.2600	0.0294	0.0161	0.0001	0.4740	0.0093	0.0278	0.1424
Mer 62	27.66	8.04	5.56	0.193	0.83	7.17	4.01	0.2627	0.0214	0.0143	0.0001	0.3989	0.0088	0.0194	0.0782
Mer 74	33.80	3.65	6.99	0.006	0.29	5.19	3.43	0.2150	0.0278	0.0171	0.0001	0.1823	0.0191	0.0354	0.1407
Mer 94	32.68	4.82	6.43	0.072	0.43	5.02	3.47	0.2462	0.0275	0.0174	0.0001	0.4012	0.0115	0.0288	0.1381
Mer 108	34.72	5.13	4.20	0.078	0.22	3.89	3.74	0.1693	0.0350	0.0214	0.0006	0.2624	0.0128	0.0234	0.1832
Mer 110	34.28	4.02	6.15	0.012	0.33	4.61	3.58	0.1976	0.0349	0.0278	0.0001	0.3195	0.0207	0.0369	0.2142
Mer 500	36.46	6.83	0.73	0.078	0.00	3.07	3.88	0.0212	0.0051	0.0176	0.0076	0.1044	0.0027	0.0034	0.0197
Mer 507	35.97	5.61	3.00	0.006	0.26	3.70	3.72	0.0851	0.0097	0.0116	0.0004	0.1862	0.0078	0.0163	0.0732

REFERENCES

Barton, C. E., Solomon, D. K., Bowman, J. R., Cerling, T. E. and Sayer, M. D., 1987, Chloride budgets of transient lakes: Lake Baringo, Naivasha and Turkana: Limnology and Oceanography, v. 32(3), p. 745–751.

Baker, B. H., Williams, L. A. J., Miller, J. A. and Fitch, F. J., 1971, Sequence and geochronology of the Kenya Rift volcanics: Tectonophysics, v.11, p. 191–215.

Bishop, W. W. and Chapman, G. R., 1970, Early Pliocene sediments and fossils from the northern Kenya Rift Valley: Nature, v. 226, p. 914–18.

Bishop, W. W., Chapman, G. R., Hill, A. P. and Miller, J. A., 1971, Succession of Cenozoic vertebrate assemblages from the Northern Kenya Rift Valley: Nature, v. 233, p. 389–394.

Bishop, W. W., 1972, Stratigraphic succession 'versus' calibration in East Africa, *in* Bishop, W. W. and Miller, J. A., eds., Calibration of Hominoid Evolution: Edinburgh, Scottish Academic Press, p. 219–246.

Bishop, W. W. and Pickford, M. H. L., 1975, Geology, fauna, and paleoenvironments of the Ngorora Formation, Kenya Rift Valley: Nature, v. 254, p. 185–192.

Brown, F. H., 1982, Tulu Bor Tuff at Koobi Fora correlated with the Sidi Hakoma Tuff at Hadar: Nature, v. 300, p. 631–635.

Brown, F. H. and Cerling, T. E., 1982, Stratigraphical significance of the Tulu Bor Tuff of the Koobi Fora Formation: Nature, v. 299, p. 212–215.

Brown, F. H. and Feibel, C. S., 1986, Revision of lithostratigraphic nomenclature in the Koobi Fora Region, Kenya: Journal of the Geological Society, v. 143, p. 297–310.

Brown, F. H., Sarna-Wojcicki, A. M., Meyer C. and Haileab, B., 1992, Correlation of Pliocene and Quaternary tephra layers between hominid-bearing strata in the Turkana Basin of East Africa and the Gulf of Aden, and some paleoclimatic implications: Quaternary International, v. 11/12, p. 55–67.

Cahen, L. and Snelling, N. J., 1966, The geochronology of Equatorial Africa: Amsterdam, North-Holland Publishing Co., 195 p.

Cerling, T. E., Brown, F. H., Cerling, B. W., Curtis, G. H., and Drake, R. E., 1979, Preliminary correlations between the Koobi Fora and Shungura Formations, East Africa: Nature, v. 279, p. 218–221.

Cerling, T. E. and Brown, F. H., 1982, Tuffaceous Marker Horizons in the Koobi Fora Region and the Lower Omo Valley: Nature, v. 299, p. 216–221.

Cerling, T. E., Brown, F. H. and Bowman, J. R., 1985, Low Temperature alteration of volcanic glass; hydration, Na, K, ^{18}O and Ar-mobility: Chemical Geology, v. 52, p. 281–293.

Chapman, G. R. and Brook, M., 1978, Chronostratigraphy of the Baringo Basin, Kenya Rift Valley, *in* Bishop, W. W., ed., Geological Background to Fossil Man: Edinburgh, Scottish Academic Press, p. 207–223.

Chapman, G. R., Lippard, S. J. and Martyn, J. E., 1978, The stratigraphy and structure of the Kamasia Range, Kenya Rift Valley: Journal of the Geological Society, v. 135, p. 265–281.

Cooke, H. B. S., 1985, Plio-Pleistocene Suidae in relation to African Hominid deposits, *in* Beden, M. et al., eds., L'environment des Hominides au Plio-Pleistocene: Paris, Mason, p. 101–117.

Dagley, P., Musset, A. E., and Palmer, H. C. 1978, Preliminary observations on the paleomagnetic stratigraphy of the area west of Lake Baringo Kenya, *in* Bishop, W. W., ed., Geological Background to Fossil Man: Edinburgh, Scottish Academic Press, p. 225–235.

Evernden, J. F., and Curtis, G. H., 1965, The potassium-argon dating of Late-Cenozoic rocks in East Africa and Italy: Current Anthropology, v. 6(4), p. 343–385.

Feibel, C. S., Brown, F. H., and McDougall, I., 1989, Stratigraphic context of fossil Hominids from the Omo Group Deposits: Northern Turkana Basin, Kenya and Ethiopia: American Journal of Physical Anthropology, v. 78, p. 595–622.

Fuchs, V. E., 1934, The geological work of the Cambridge expedition to the East African Lakes. Part I: Eastern Rift Valley in Kenya Colony: Geological Magazine, v. 71, p. 97–112.

Fuchs, V. E., 1950, Pleistocene events in the Baringo Basin: Geological Magazine, v. 87, p. 149–174.

Gregory, J. W., 1921, The Rift Valleys and geology of East Africa: London, Seely Service and Co., 479 p.

Haileab, B., 1988, Characterization of tephra from the Shungura Formation, southwestern Ethiopia [M.S. Thesis]: University of Utah, 130 p.

Haileab, B., and Brown, F. H., 1992, Turkana Basin–Middle Awash Valley correlations and the age of the Sagantole and Hadar Formations: Journal of Human Evolution, v. 22, p. 453–468.

Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L. E., Smith, A. G., Smith, D. G., 1989, A Geological Time Scale: Cambridge, Cambridge University Press, 263 p.

Harris, J. M., Brown, F. H., Leakey, M. G., Walker, A. C., and Leakey, R. E., 1988, Pliocene and Pleistocene Hominid bearing sites from west of Lake Turkana, Kenya: Science, v. 239, p. 27–33.

Hill, A., 1985, Early hominid from Baringo, Kenya: Nature, v. 315, p. 222–224.

Hill, A., Drake, R., Tauxe, L., Monaghan, M., Barry, J. C., Behrensmeyer, A. K., Curtis, G., Jacobs, B. F., Jacobs, L., Johnson, N., and Pilbeam, D., 1985, Neogene Paleontology and Geochronology of the Baringo Basin, Kenya: Journal of Human Evolution, v. 14, p. 759–773.

Hill, A., Curtis, G., and Drake, R., 1986, Sedimentary Stratigraphy of the Tugen Hills, Baringo, Kenya, *in* Frostick L. E., Renault, R. W., Reid, I., and Tiercelin, J. J, eds., Sedimentation in the African Rifts: Geological Society Special Publication no. 25, p. 285–295.

Hill, A., Behrensmeyer, A. K., Brown, B., Deino, A., Rose, M., Saunders, J., Ward, S., and Winkler, A., 1991, Kipsaramon: a lower Miocene hominoid site in the Tugen Hills, Baringo District, Kenya: Journal of Human Evolution, v. 20, p. 67–75.

Hill, A., Ward, S., Deino, A., Curtis, G., and Drake, R., 1992, Earliest Homo: Nature, v. 355, p. 719–722.

King, B. C., 1978, Structural and volcanic evolution of the Gregory Rift Valley, *in* Bishop, W. W., ed., Geological Background to Fossil Man: Edinburgh, Scottish Academic Press, p. 29–54.

Martz, M. A., 1979, Petrology and chemistry of tuffs from the Shungura Formation, southwestern Ethiopia [M.S. Thesis]: University of Utah, 82 p.

Martyn, J. E., 1967, Pleistocene deposits and new fossil localities in Kenya: Nature, v. 215, p. 476–480.

McCall, G. J. H., 1967, Geology of the Nakuru-Thomson's Falls-Lake Hannington area: Report No. 78, Geological Survey of Kenya, 122 p.

McCall, G. J. H., Baker, B. H. and Walsh, J., 1967, Late Tertiary and Quaternary sediments of the Kenya Rift Valley, *in* Bishop, W. W. and Clark, J. D., eds., Background to Evolution in Africa: Chicago, University of Chicago Press, p. 191–220.

Pickford, M., 1975, Late Miocene sediments and fossils from the Northern Kenya Rift Valley: Nature, v. 256, p. 279–284.

Pickford, M., 1978a, Geology, paleoenvironments and vertebrate faunas of the Mid-Miocene Ngorora Formation, Kenya, *in* Bishop, W. W., ed., Geological Background to Fossil Man: Edinburgh, Scottish Academic Press, p. 237–262.

Pickford, M., 1978b, Stratigraphy and Mammalian Paleontology of the Late Miocene Lukeino Formation, Kenya, *in* Bishop, W. W., ed., Geological Background to Fossil Man: Edinburgh, Scottish Academic Press, p. 263–278.

Pickford, M., Johanson, D. C., Lovejoy, C. O., White, T. D., and Aronson, J. L., 1983, A hominoid humeral fragment from the Pliocene of Kenya: American Journal of Physical Anthropology, v. 60, p. 337–346.

Pickford, M., Senut, B., Poupeau, G., Brown, F. H., and Haileab, B., 1991, Correlation of tephra layers from the Western Rift Valley (Uganda) to the Turkana Basin (Ethiopia/Kenya) and the Gulf of Aden: Comptes Rendus Academie Science, Paris, Serie II, v., p. 223–229.

Powers, D. W., 1980, Geology of Mid-Pliocene sediments of the lower Kerio-River Valley, Kenya [Ph. D. Thesis]: Princeton University, 165 p.

Sarna-Wojcicki, A. M., Meyer, C. E., Roth, P. H., and Brown, F. H., 1985, Ages of tuff beds at East African early hominid sites and sediments in the Gulf of Aden: Nature, v. 313, p. 306–308.

Shackleton, R. M., 1978, Structural development of the East African rift system, *in* Bishop, W. W., ed., Geological Background to Fossil Man: Edinburgh, Scottish Academic Press, p. 19–28.

Tauxe, L., Monaghan, M., Drake, R., Curtis, G., and Staudigel, H., 1985, Paleomagnetism of Miocene East African rift sediments and calibration of the geomagnetic reversal time scale: Journal of Geophysical Research, v. 40, p. 4639–4646.

Walsh, J., 1969, Geology of Eldama Ravine-Kabarnet area: Report No. 83, Geological Survey of Kenya, 48 p.

Wood, B., 1992, Old bones match old stones: Nature, v. 355, p. 678–679.